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What is time?

How do we make time?

How do we distribute time?

How do we knew what time it is?

Tech Talk to the IAB

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Agenda:

- What is a Clock?
- Time / Frequency terminalogy
- Precision vs. Accuracy
- How long is a second?
- International and National Timescales, TAI, UTC, UT2
- Lenght of a day, or the earth do not rotate at constant speed
- Leap seconds
- UTC, TAI is coordinated by the BIPM in Paris
- World official time, National time, Daylight savings
- Overview of atomic clock technologies
- Example of UTC(k) lab frequency/time generation
- Time transfer methods used for UTC
- Reality check, source of time, fiber networks, IP network observations
- Comparison of different oscillators used in clocks and other devices
- Host issues
- NTP, IEEE 1588, TicToc
- Improve time services over the Internet
- Vint's Internet to Mars

Special Thanks To:

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- Yaakov Stein, Rad
- Sprint ATL
- Everyone at the IETF
- Everyone else that contributed

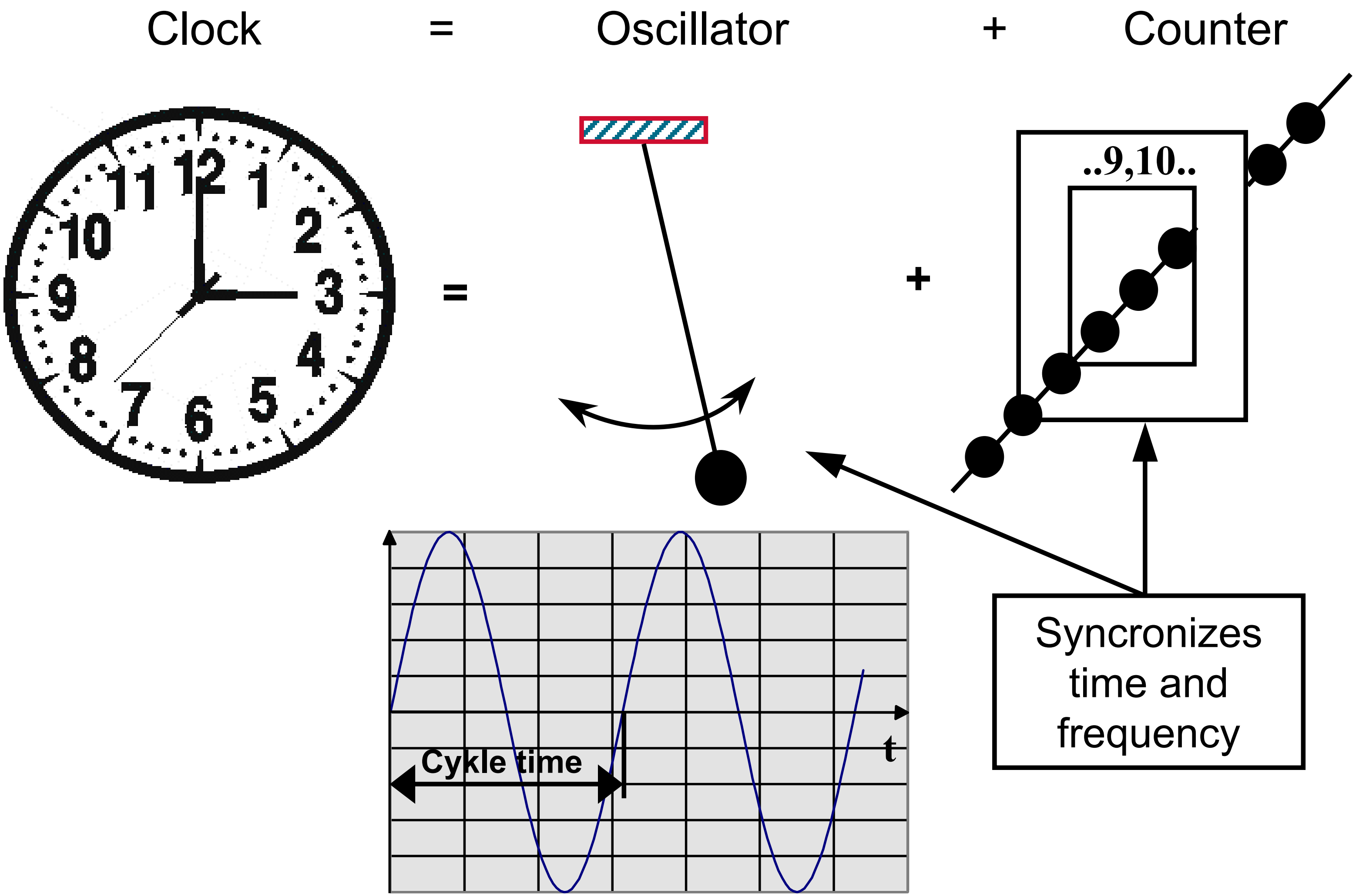
- (And Kurtis who talked me in to doing this
  presentation...)

Disclaimer!

-This is not my job....

-This presentation is to explain some of the basics of time, timekeeping, time distribution and things related to transfer time over the Internet

What is a clock?



Variations in the cyckle time causes phase and time errors

Terminology, #1

- Date
  - Year, month, day, hour, minute, second, ...
- Phase
  - Time elapsed since a given reference time
- Time Intervall
  - Time between two phases or dates
- Frequency
  - Number of events/cycles per second
- Time Scale
  - System for defining dates in a unique way

Terminology, #2

- **Difference**
  - The difference between two values
- **Error**
  - Differance between measured and expected value
- **Deviation**
  - The difference to the nominal value
- **Relative error**
  - The difference between expected value divided by the nominal
- **Jitter**
  - Phase difference between a series of observations
- **Wander**
  - Jitter with f < 10 Hz; f = nHz => yearly variations

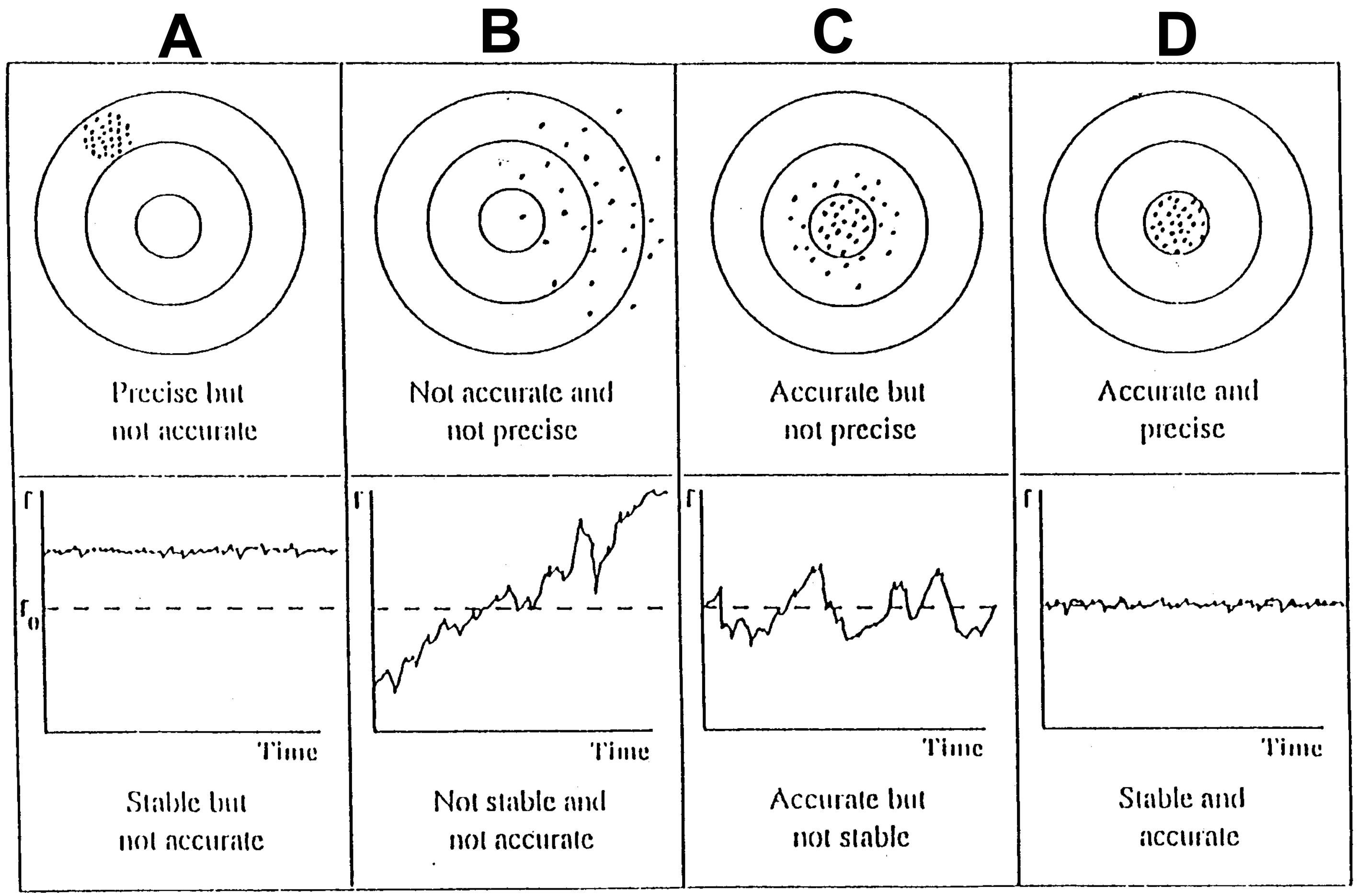
Terminology, #3

- **Ageing**
  - Changes due to mechacical/physical resons that follows a pattern as time goes by
- **Drift**
  - Changes in frequency regardless of cause
- **Primary Reference**
  - Reference that corresponds to measured value-definition, within specified error range, without use of any external source
- **Seconday Reference**
  - Reference that requires external calibration

Precision vs. Accuracy, #1

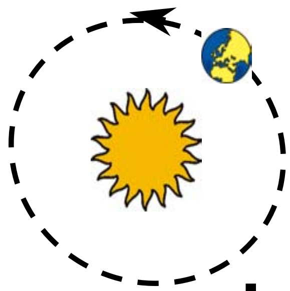
- **Accuracy**
  - How close a value is to it’s definition
- **Precision**
  - How close to eachother a series of mesurements are
- **Stability**
  - The change of a value within a defined time-interval

Accurate, precise and stable #2



How long is a second? #1

- **Before 1956: Average solar eclipse day**
  1 second = One averge sun day / 86400



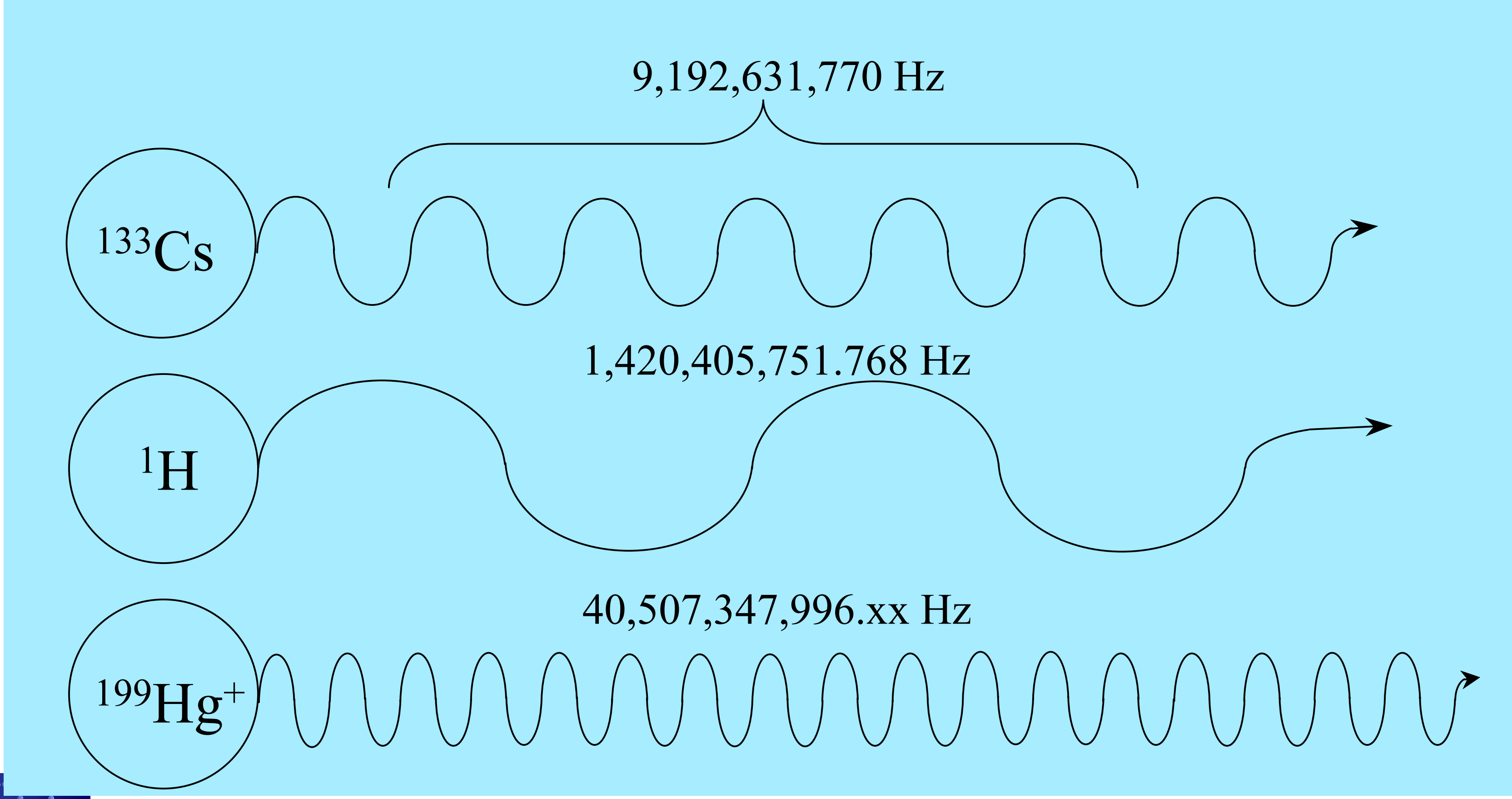
- **Between 1956 and 1967: Efemeridsecond**
  1 second =
  One tropical year, year 1900 / 31 556 925 9747 =
  365,2422 average sun day

(24*60*60*365=31 536 000)

How long is a second? #2

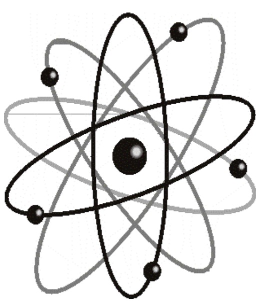
- **After 1967: Atomic second**

“The second is the duration of 9,192,631,770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of the undisturbed cesium-133 atom” (State transition 3-4)



Time Scale #1

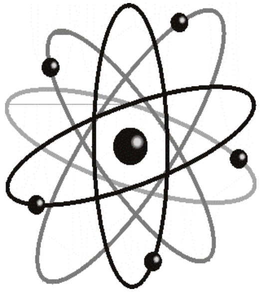
- **UT1 (Universal Time)**
  - Based on average sun second (solar eclipse day)
  - 00.00 UT1 is midnight a 0 degrees
  - GMT (Greenwich Mean Time) is based on UT1
- **TAI (International Atomic Time)**
  - Based on the atomic second
  - Based on solar eclipse second year 1900
  - A weighted average of about 240 atomic clocks
  - Steered towards EAL (primary frequency standards)
  - TAI » UT1 January 1, 1958
  - TAI » UT1 + 33 s 2008



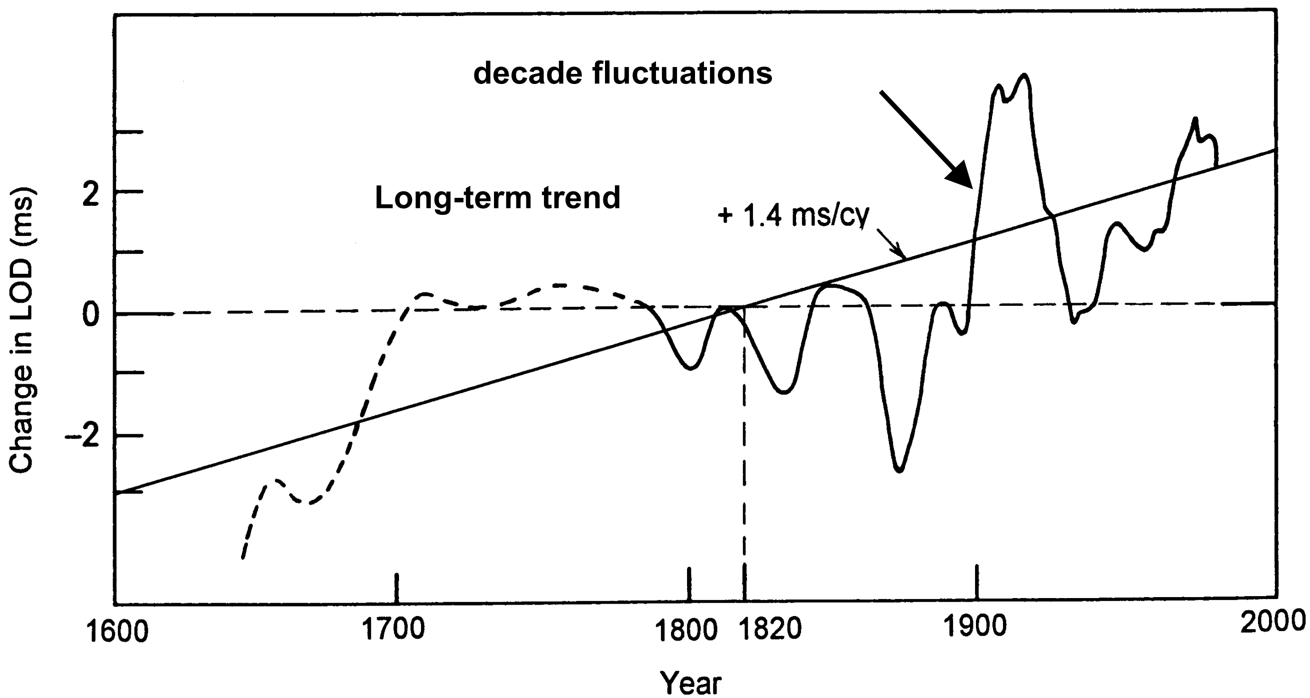
Time Scale #2

- **UTC (Universal Time Coordinated)**
  - **Based on the atomic second (TAI)**
  - **Compensated for changes in earth rotation speed**
  - **00.00 UTC is midnight at zero degrees**
  - **UTC - TAI = N secobds (N integer)**
  - **| UTC - UT1 | < 0,9 seconds**
  - **N is named ”Leap Seconds”**
  - **Leap seconds can be both added and subtracted**
  - **Last leap second was added 1 Jan 2006**

    (To adjust last minute of day has 59, 60 or 61 seconds)

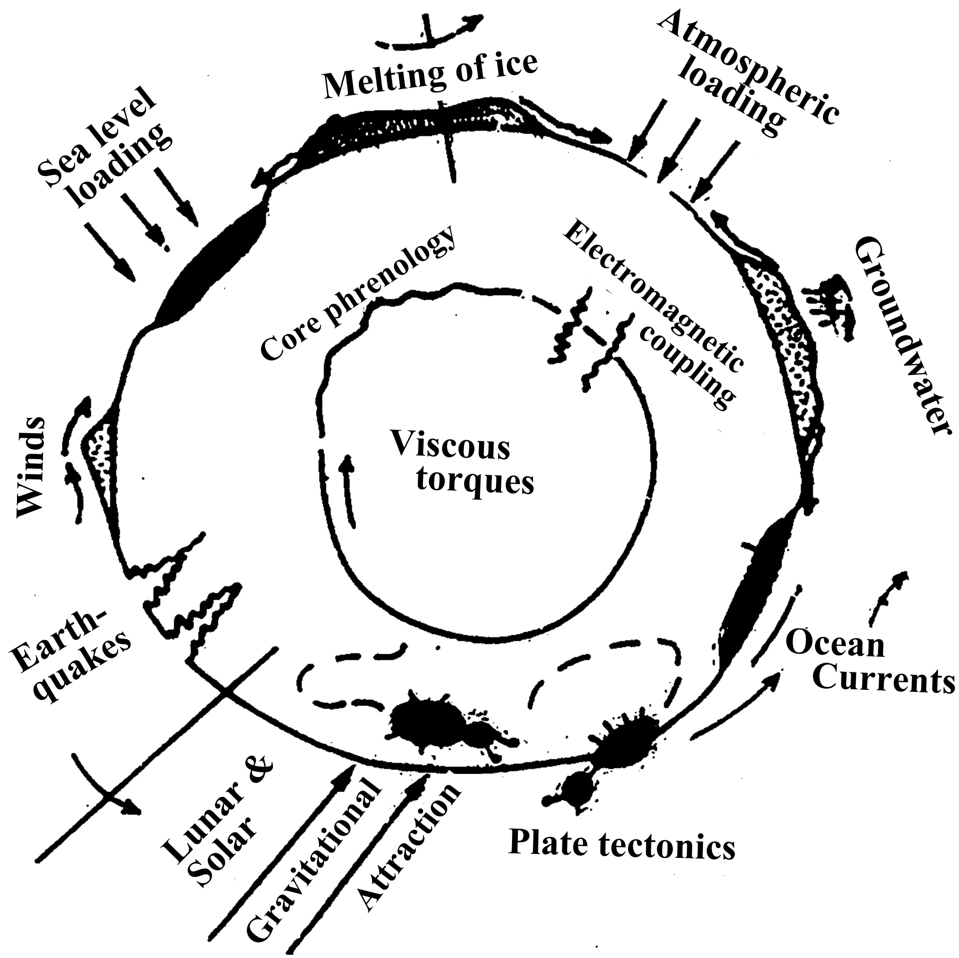


Length of Day (LOD) since 1600



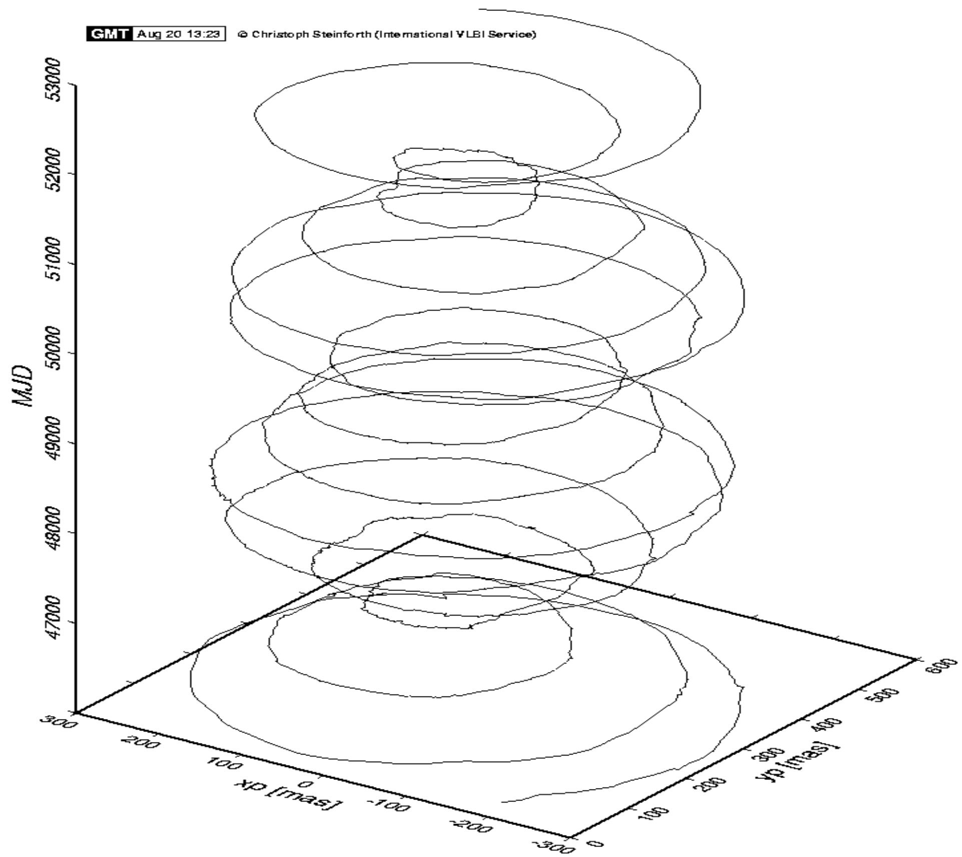
After F.R. Stephenson and L.V. Morrison, *Phil. Trans. R. Soc. London* **A313**, 47 – 70 (1984)

Schematic Illustration Of The Forces That Perturb The Earth's Rotation



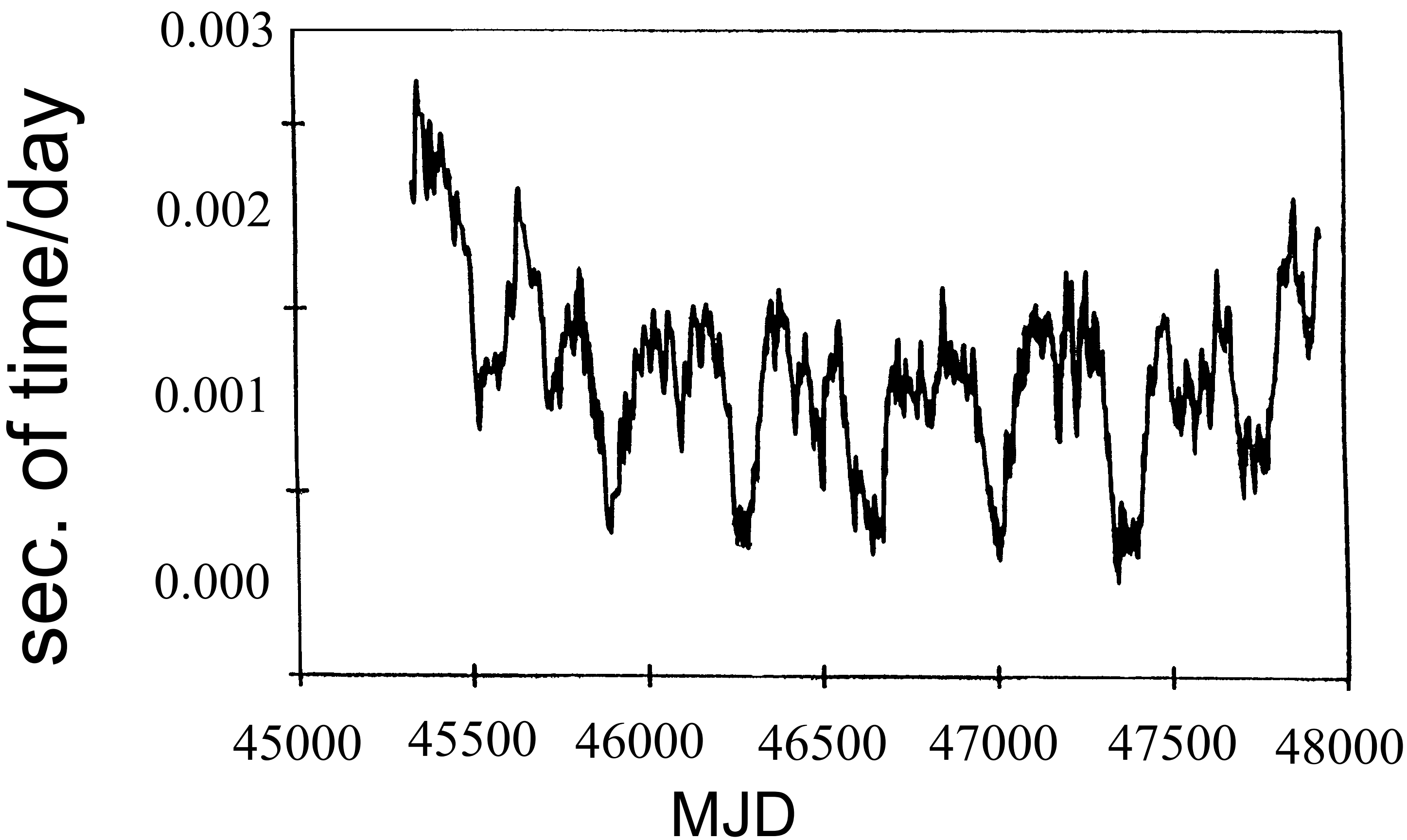
Source: Thomas Gold, *Nature*

Polar Motion (1984-2002)



Source: http://giub.geod.uni-bonn.de/vlbi/IVS-AC/combi-all/start.html

Variations In Length Of Day (LOD)



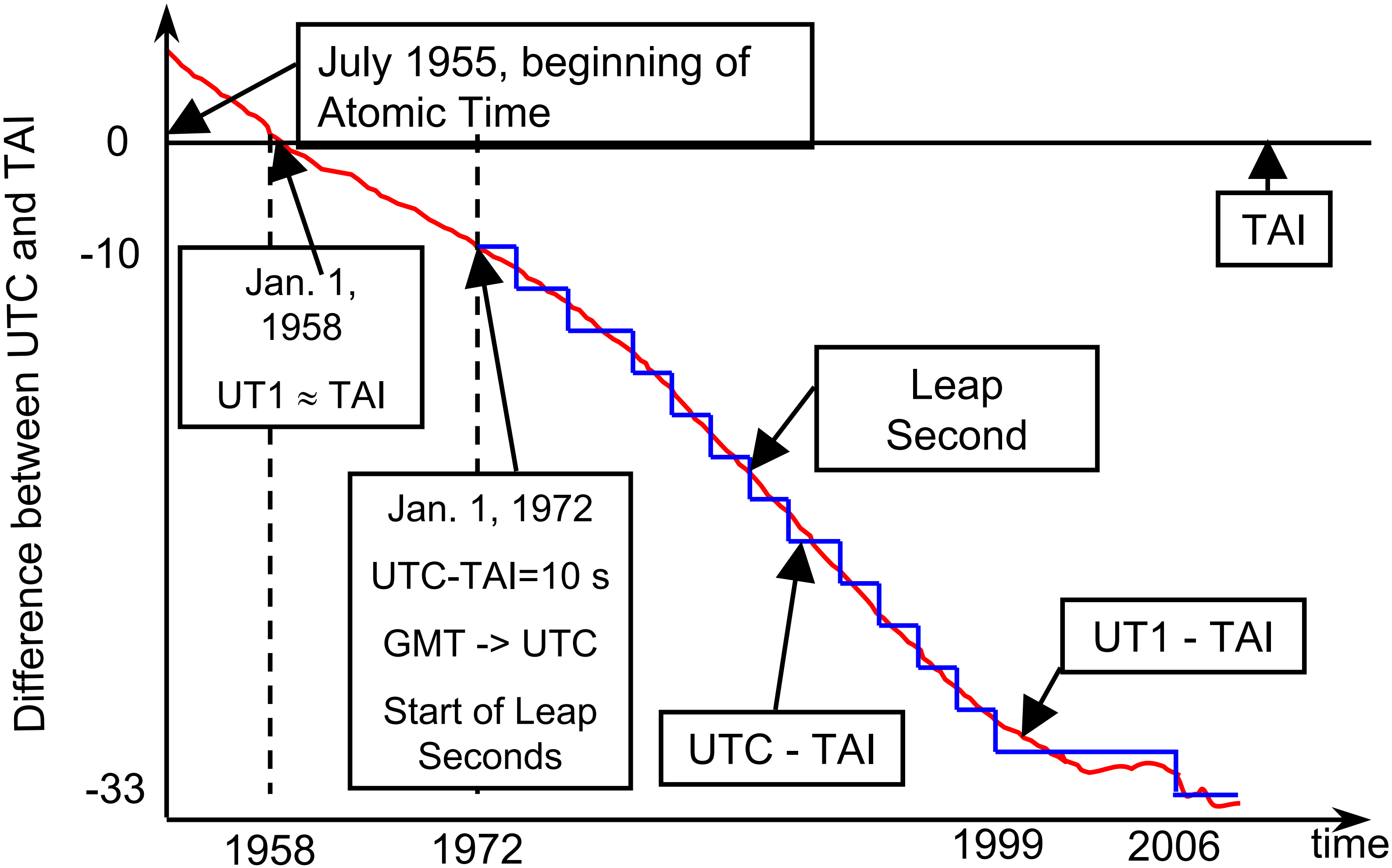
- Earth has lost 14 hours since 1815 BC

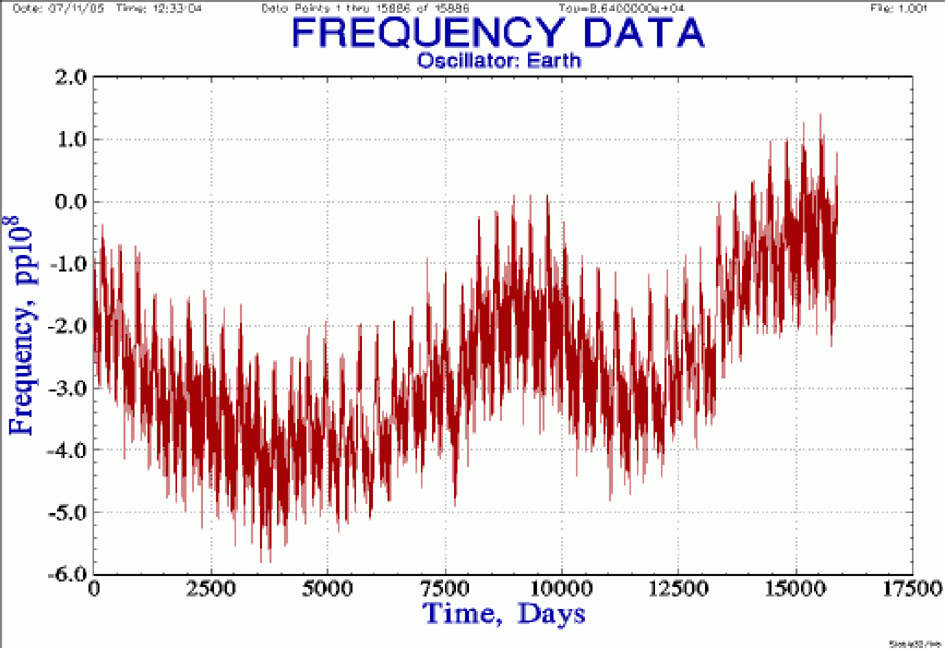
  From Chinese solar-eclipse records

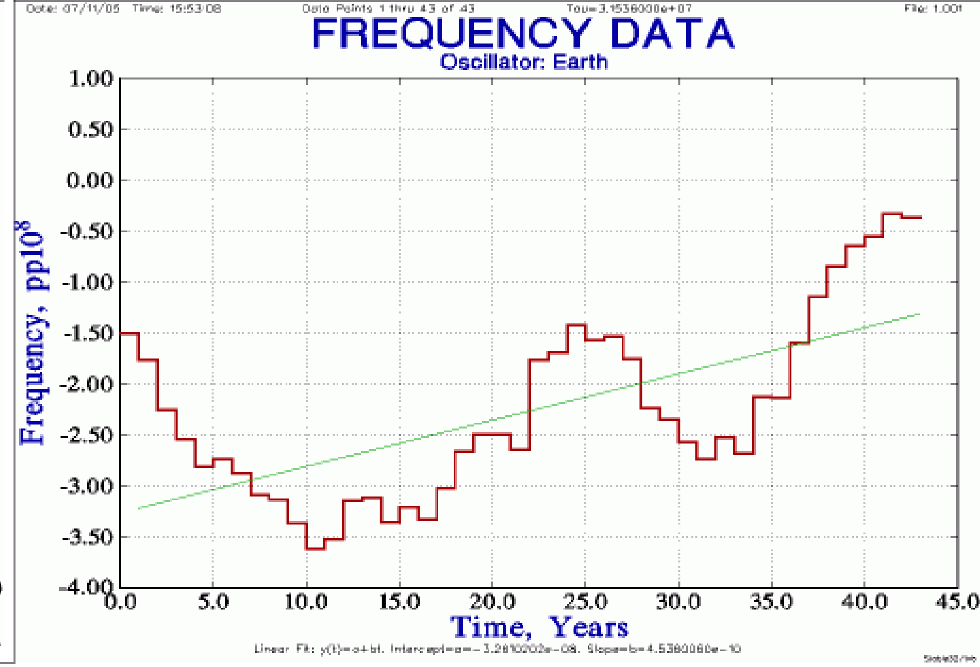
- ~100 million years ago, a day lasted only 20 hours

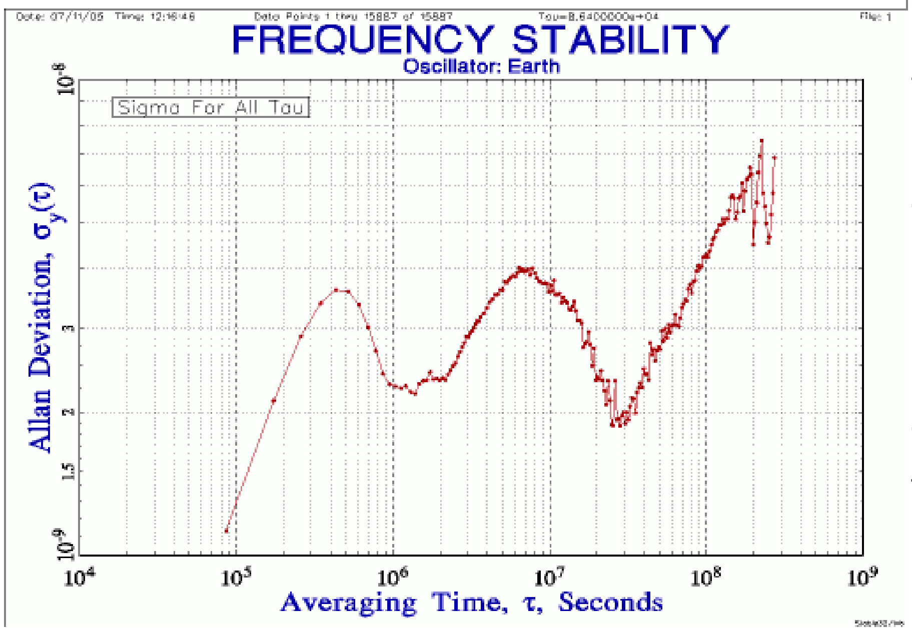
  From fossilized nematodes

Summary UT1, TAI och UTC









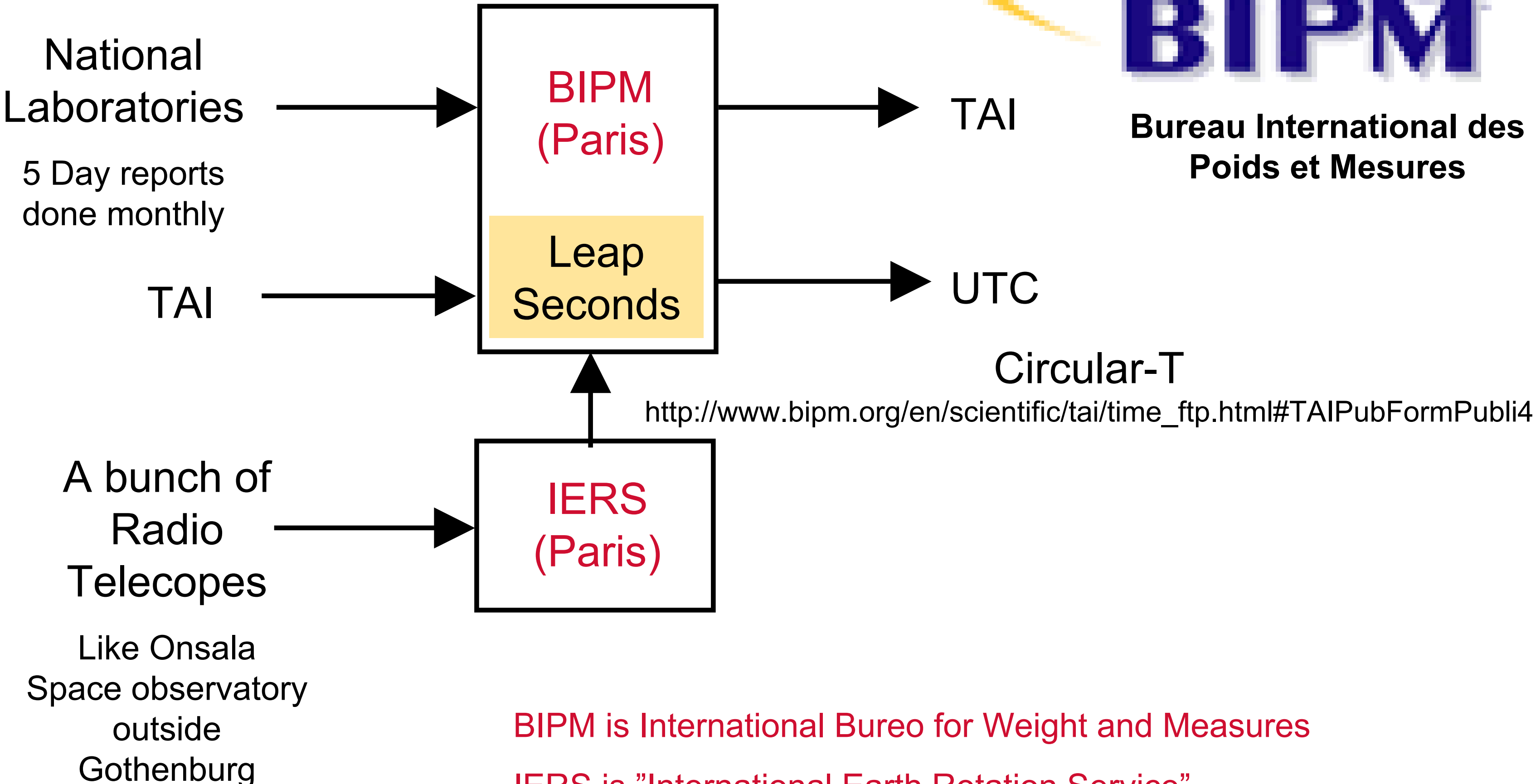
"During the 40 year test period, the average frequency of the oscillator was about a few parts in 10^8th below the nameplate value.

There appears to be no fine or coarse frequency adjustment on earth. In cases like this one must either use an external frequency synthesizer, or phase micro stepper, to correct for the frequency error. Or one can post-process the data and apply corrections in software. The lack of electronic frequency adjustment prevents it from being used in a GPSDO."

Earth as an oscillator

Source: Tom Van Bank, http://www.leap second.com/museum/earth/

BIPM och UTC #1



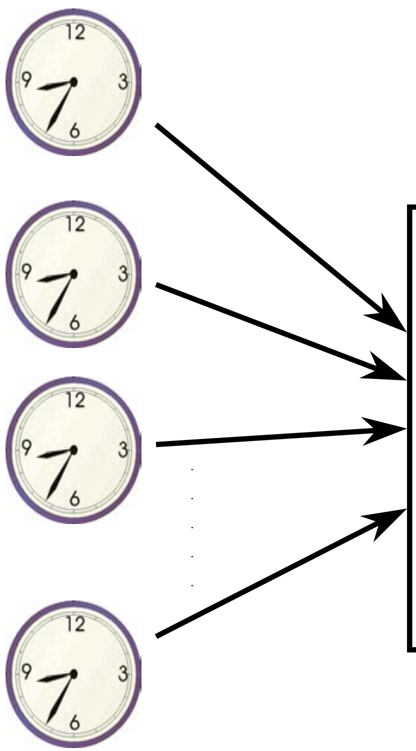
Bureau International des Poids et Mesures

BIPM is International Bureo for Weight and Measures

IERS is ”International Earth Rotation Service”

BIPM och UTC #2

Steered time scales such as UTC(USNO), UTC(SP), UTC(K)
All are Atomic Time, as they all get time from atomic oscillations,
And usually all UTC(K) are within 1us of each other



Algorithm ”ALGOS”:

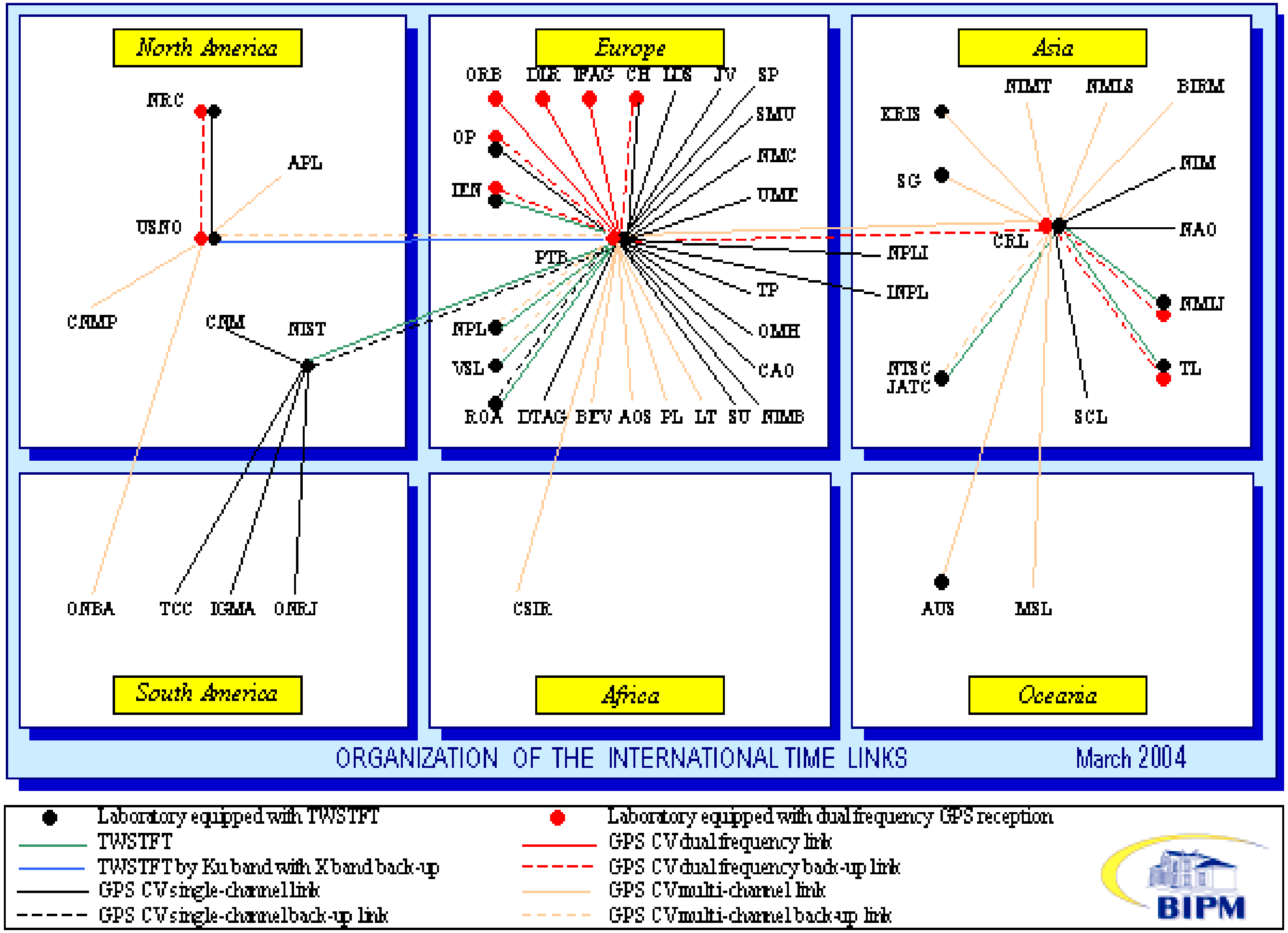
- Remove outlayers
- Clocks are weighted based on stability
- Computes drift for all clocks compared to TAI
- Computes UTC-UTC(K)
- Output in Circular-T

08:35:10 UTC
08:35:43 TAI

Paper Clocks:

TAI och UTC

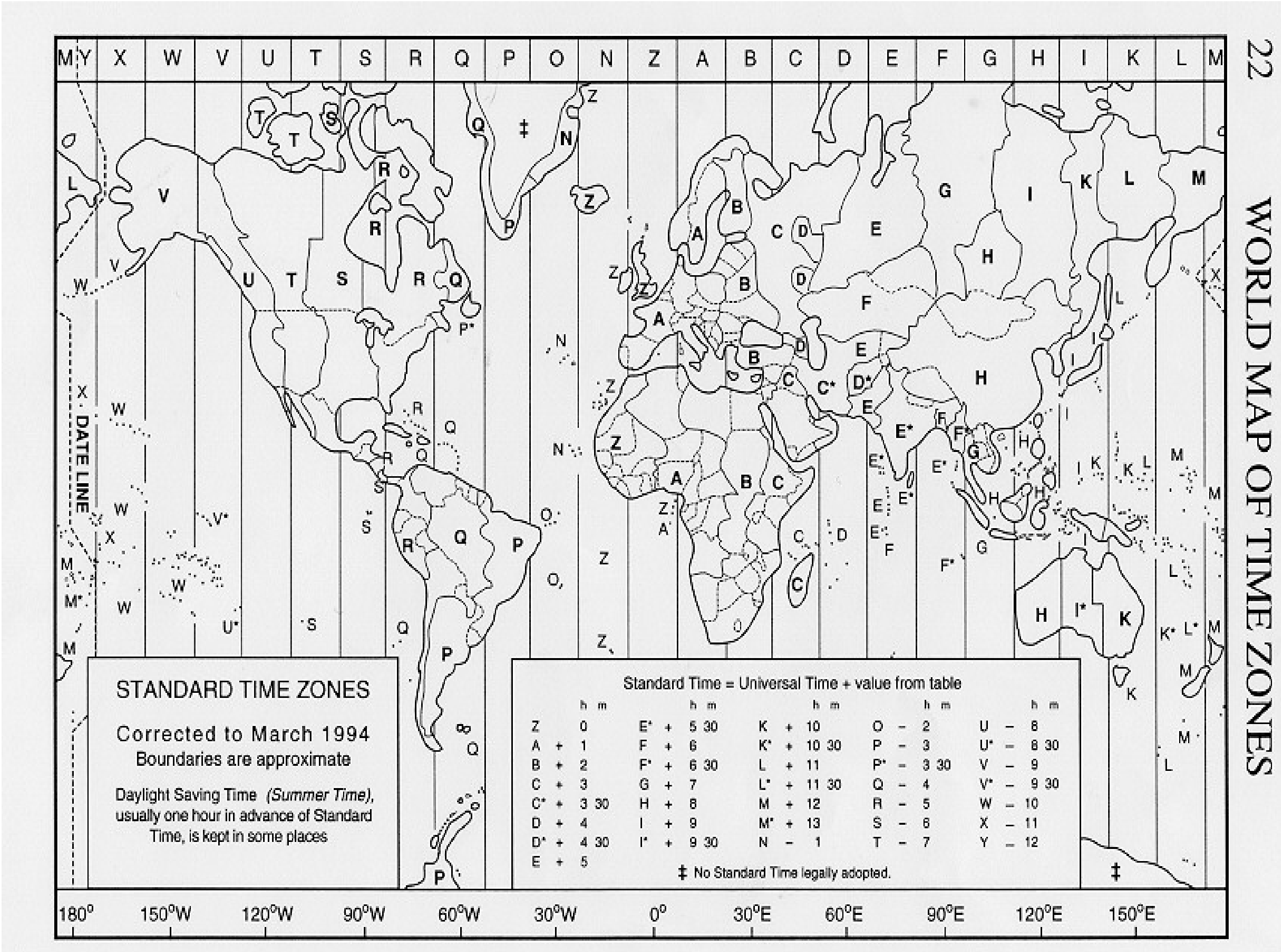
National UTC(K) labs and transfer links



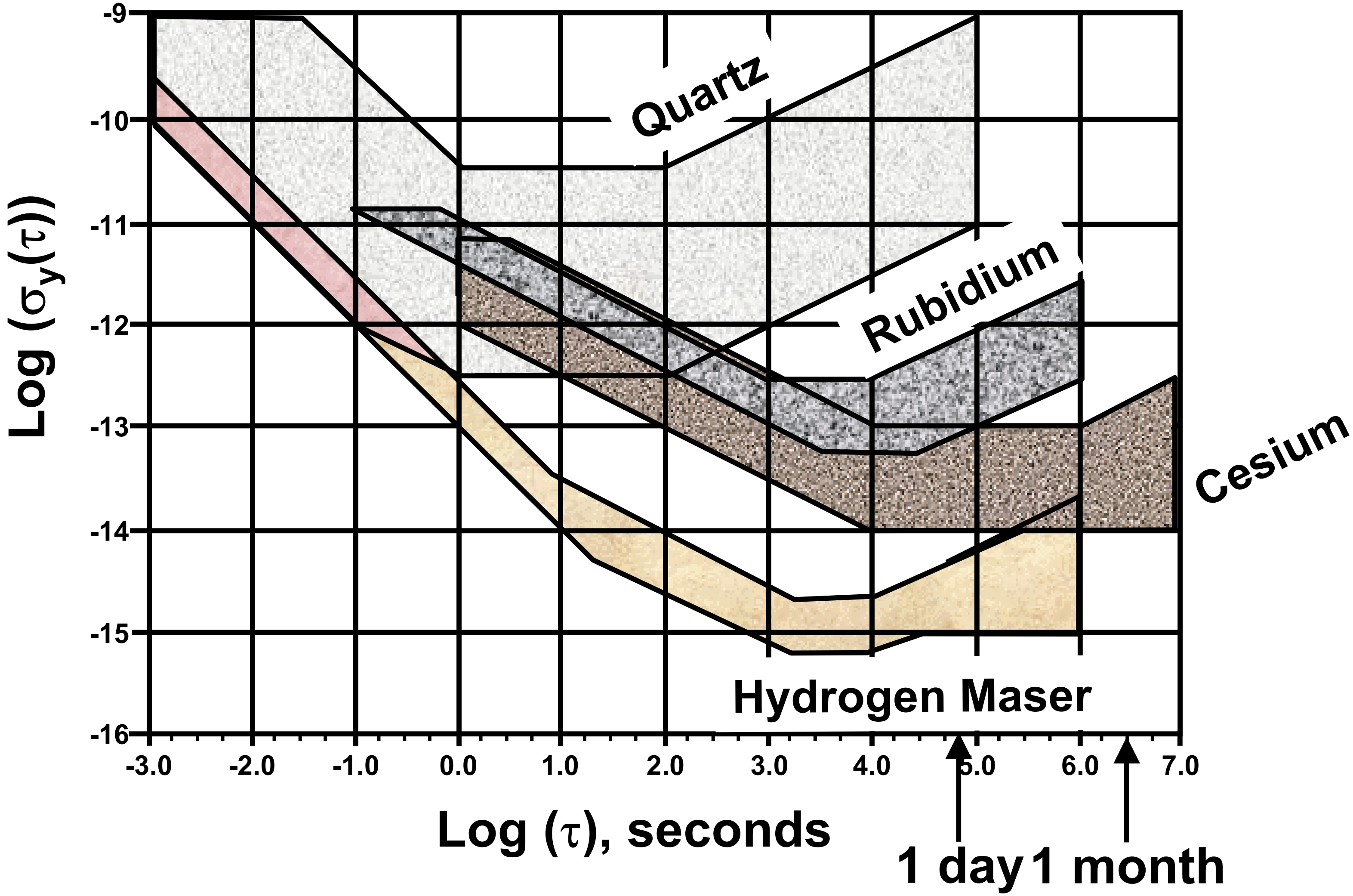
Official world time

- Geographical local timescales up to 1884
- 1884 GMT is introduced as time world wide
  (Still local variations up to around 1900)
- GMT was in use until 1972
- From 1972 is UTC used as the timescale in most countries.
- Each country decides on offset from UTC
- Each country decides on the use off daylight savings. (Stupid, cows don't wear watches!)
  - Sweden UTC+1h (+2h for DST)

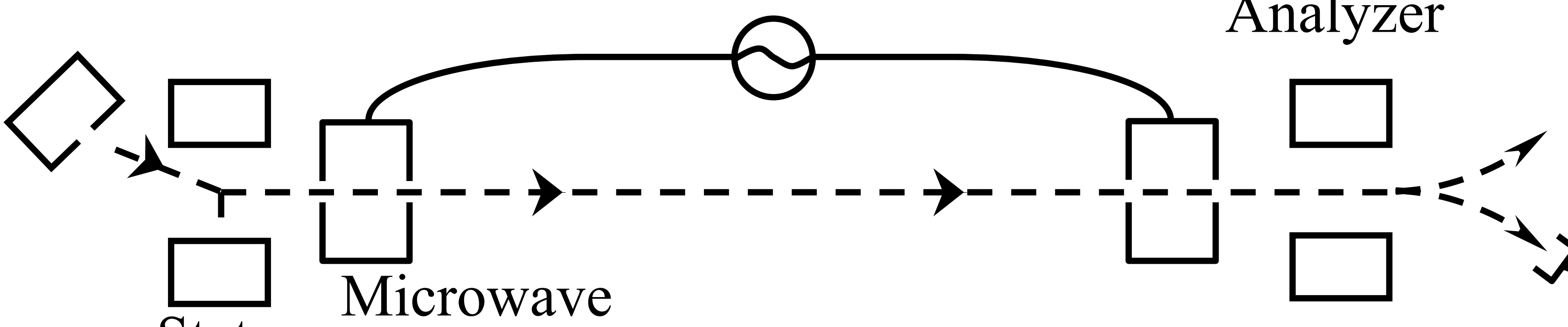
World Time Zones



Stability of Various Frequency Standards
Allan deviation, Log-Log scale



Traditional Cesium Atomic Clock



Ramsey Separated Oscillatory Fields

Hydrogen Maser Frequency Standard

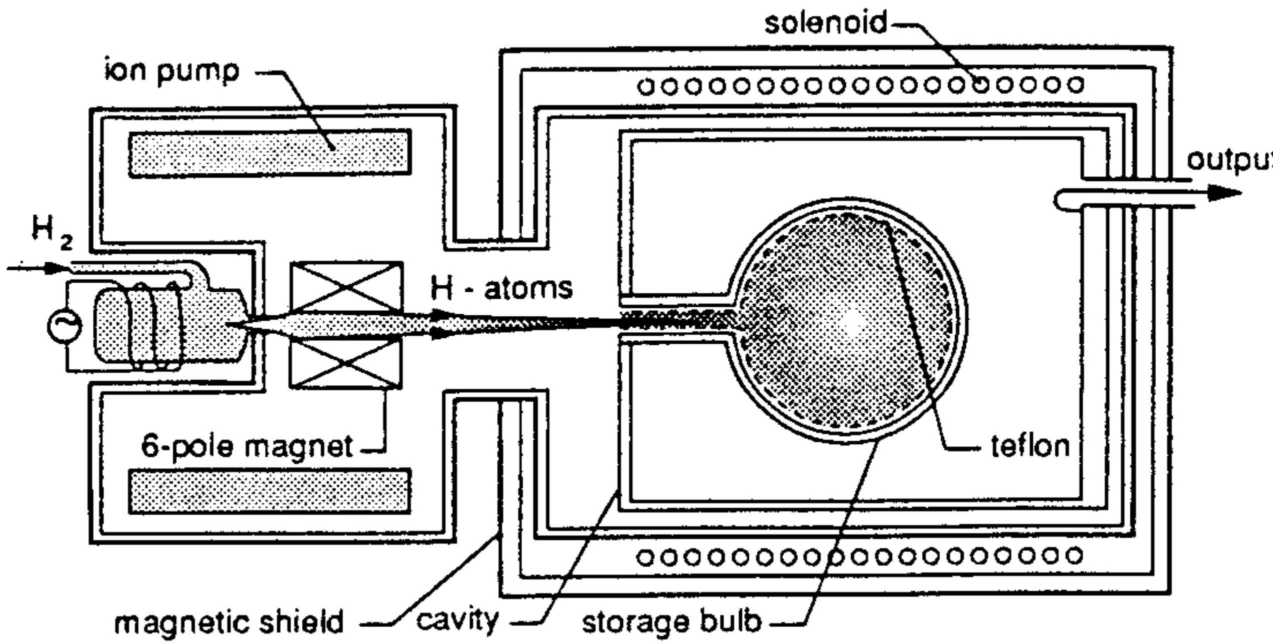
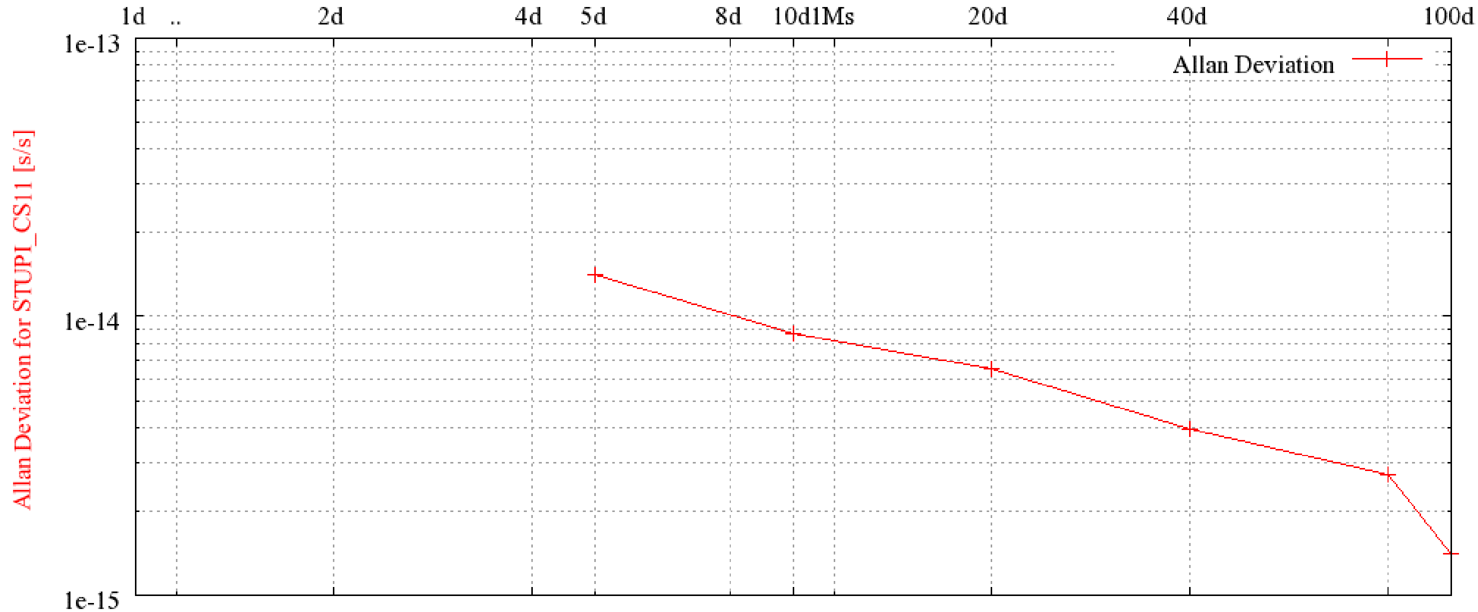


Figure 11.2 The basic elements of a hydrogen maser

F.G. Major Springer, “The Quantum Beat”, 1998

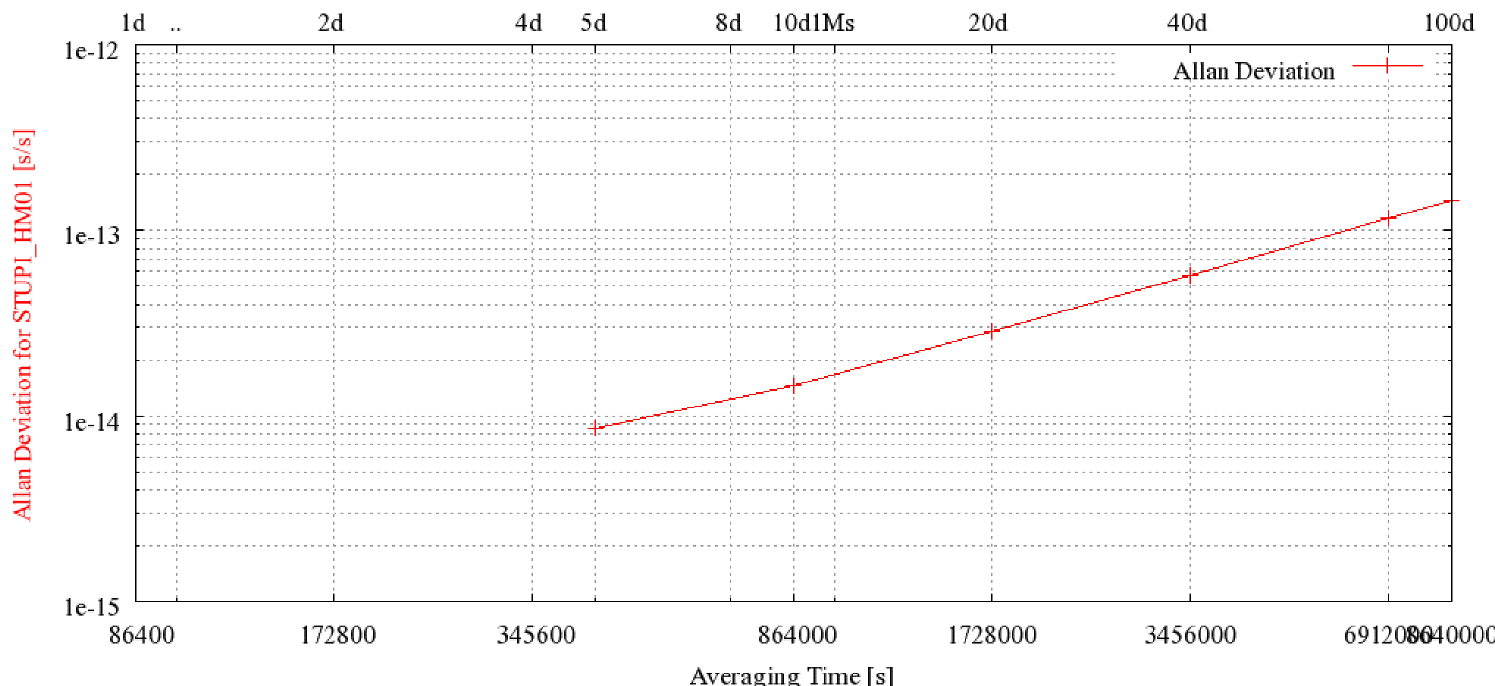
CS11

Year 2006, Clk STUPI_CS11, Ref UTC, Link: SP_BIPM-SP_GPS9-STUPI_GPS9-STUPI_UTC-STUPI_TIC0111

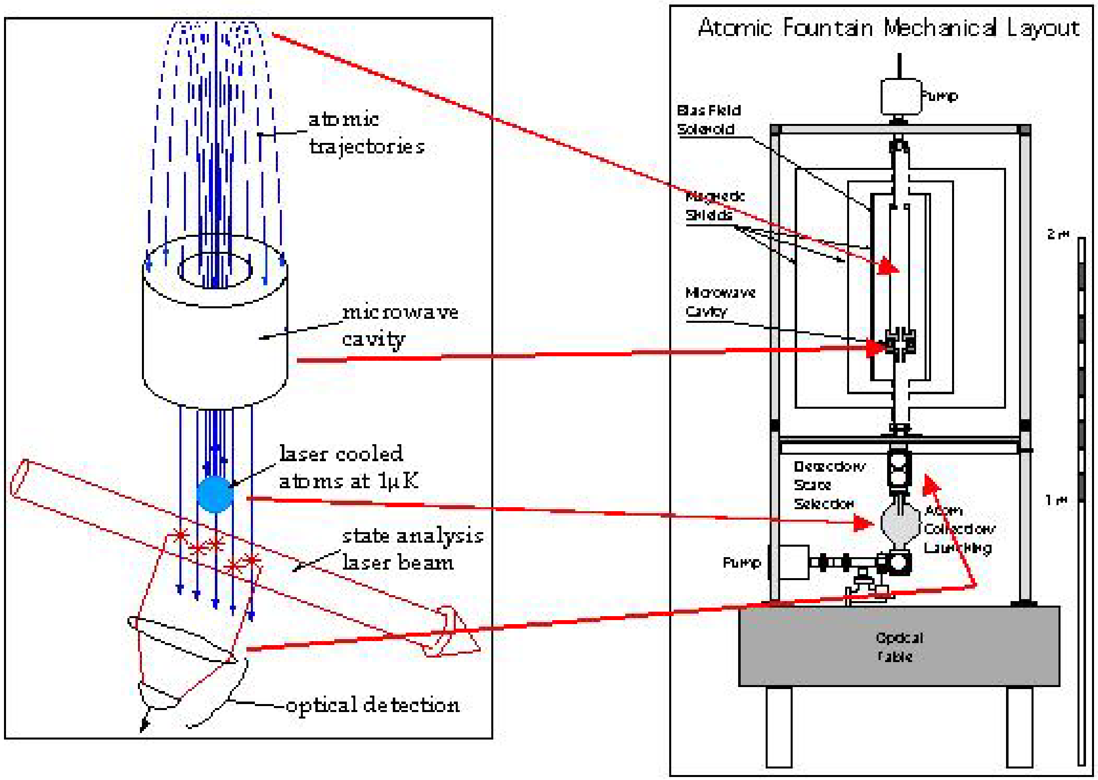


HM01

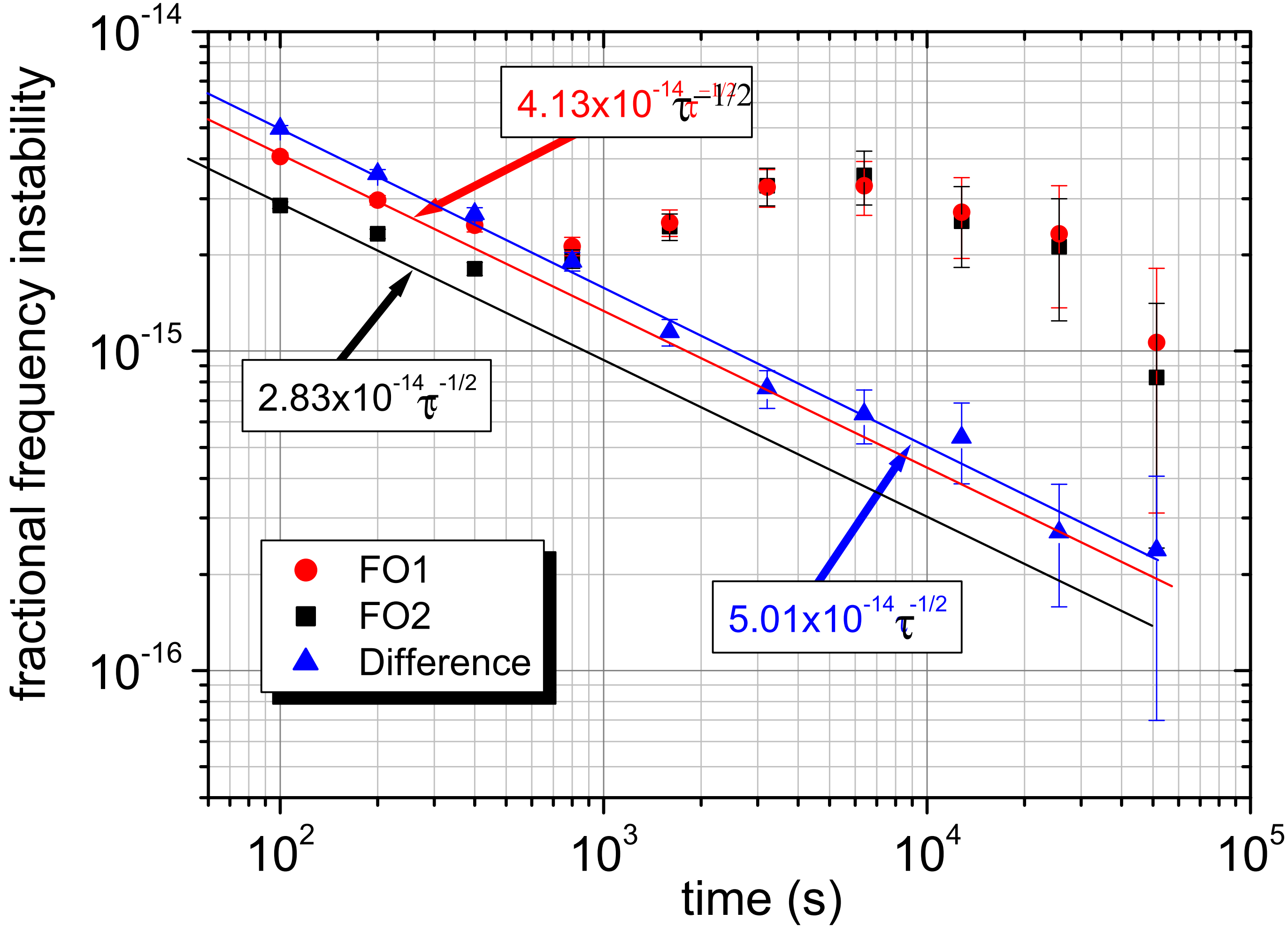
Year 2006, Clk STUPI_HM01, Ref UTC, Link: SP_BIPM-SP_GPS9-STUPI_GPS9-STUPI_UTC-STUPI_TIC0114



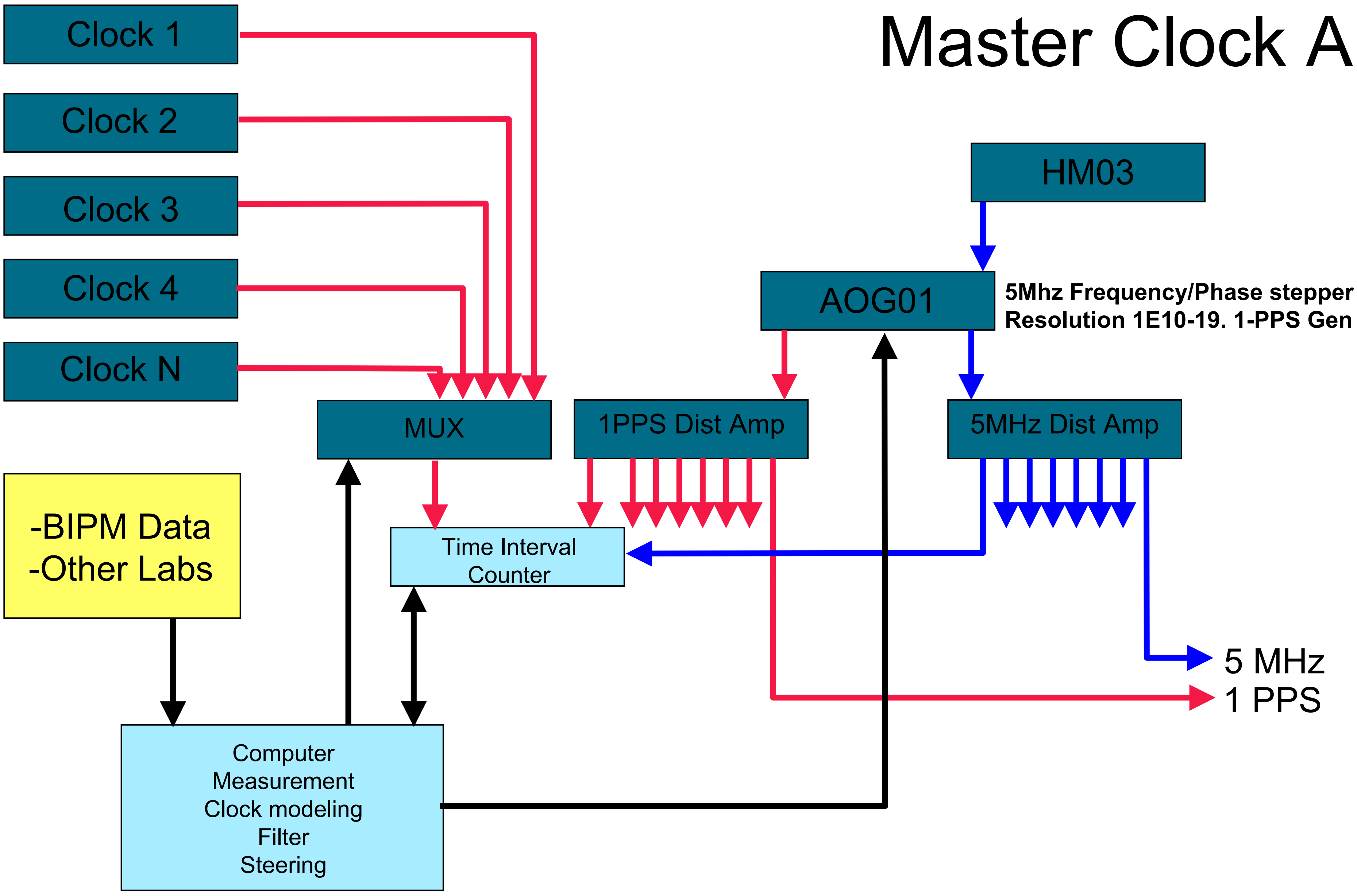
Cesium Fountain Frequency Standard



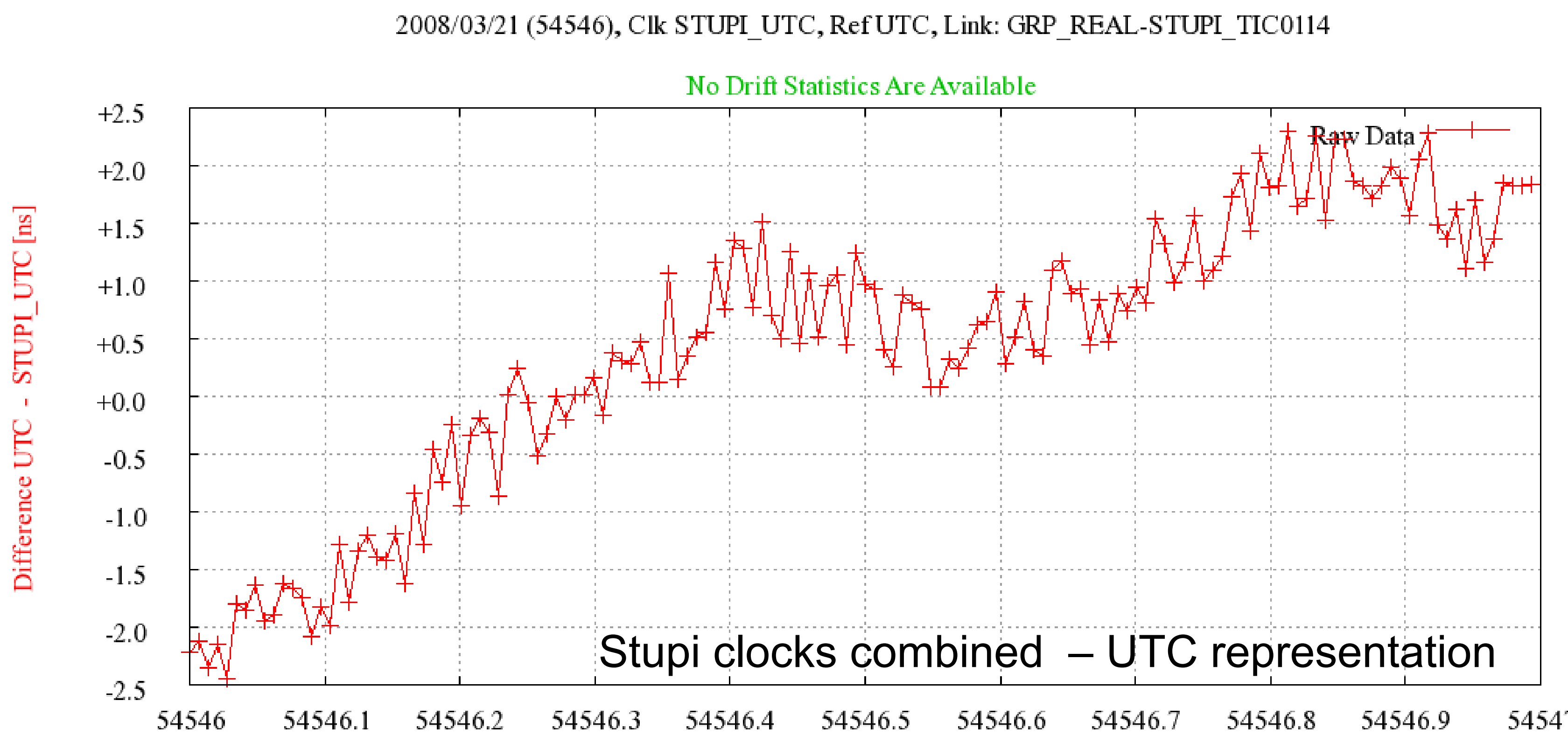
Cesium Fountain Stability (Paris)



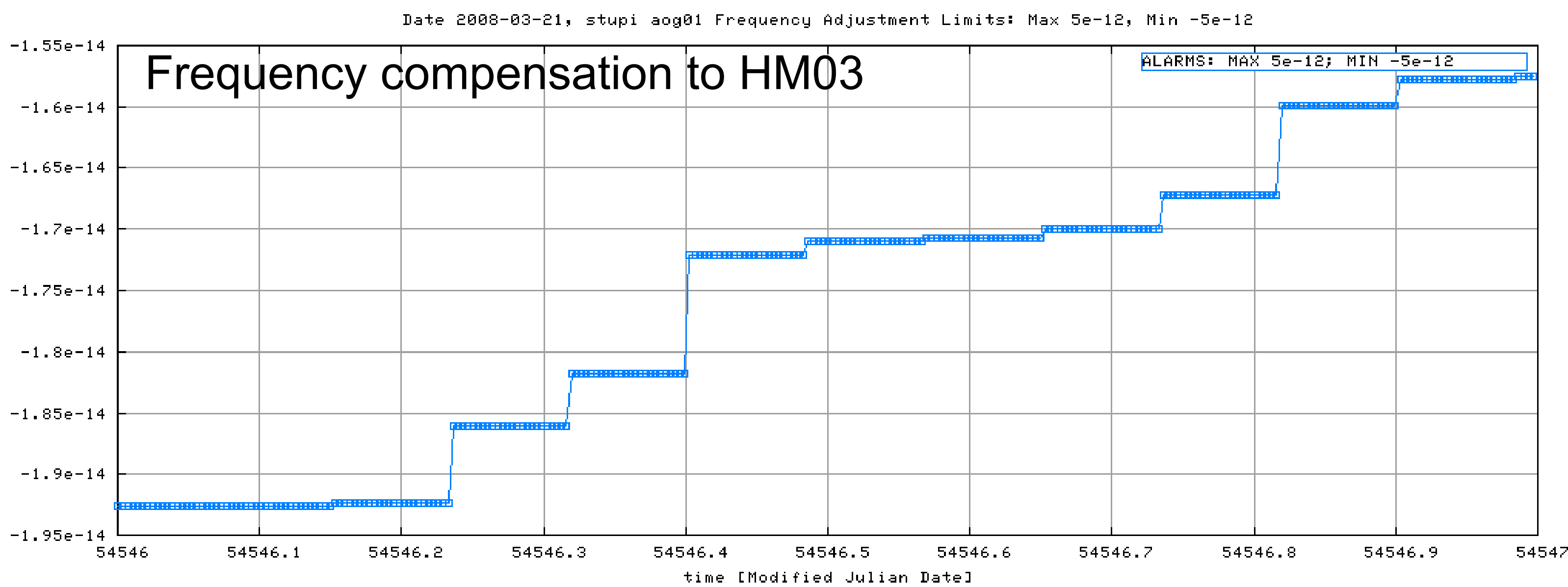
Master Clock A



"Typical Time Factory Setup"



2008/03/21 (54546), Clk STUPI_UTC, Ref UTC, Link: GRP_REAL-STUPI_TIC0114
No Drift Statistics Are Available
Raw Data
Difference UTC - STUPI_UTC [ns]
+2.5
+2.0
+1.5
+1.0
+0.5
+0.0
-0.5
-1.0
-1.5
-2.0
-2.5
54546
54546.1
54546.2
54546.3
54546.4
54546.5
54546.6
54546.7
54546.8
54546.9
Stupi clocks combined – UTC representation

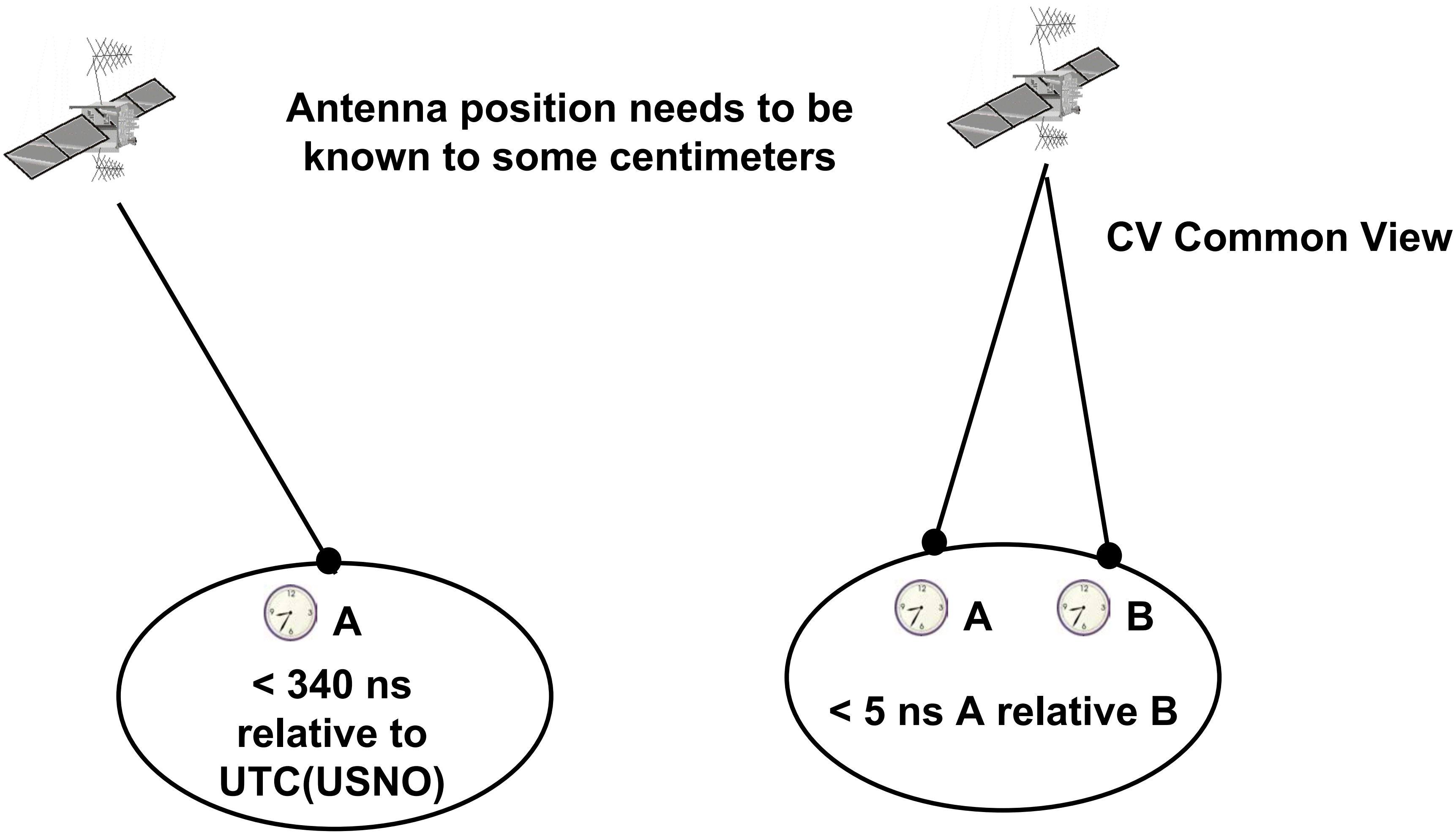


Date 2008-03-21, stupi aog01 Frequency Adjustment Limits: Max 5e-12, Min -5e-12
Frequency compensation to HM03
ALARMS: MAX 5e-12; MIN -5e-12
-1.55e-14
-1.6e-14
-1.65e-14
-1.7e-14
-1.75e-14
-1.8e-14
-1.85e-14
-1.9e-14
-1.95e-14
54546
54546.1
54546.2
54546.3
54546.4
54546.5
54546.6
54546.7
54546.8
54546.9
54547
time [Modified Julian Date]

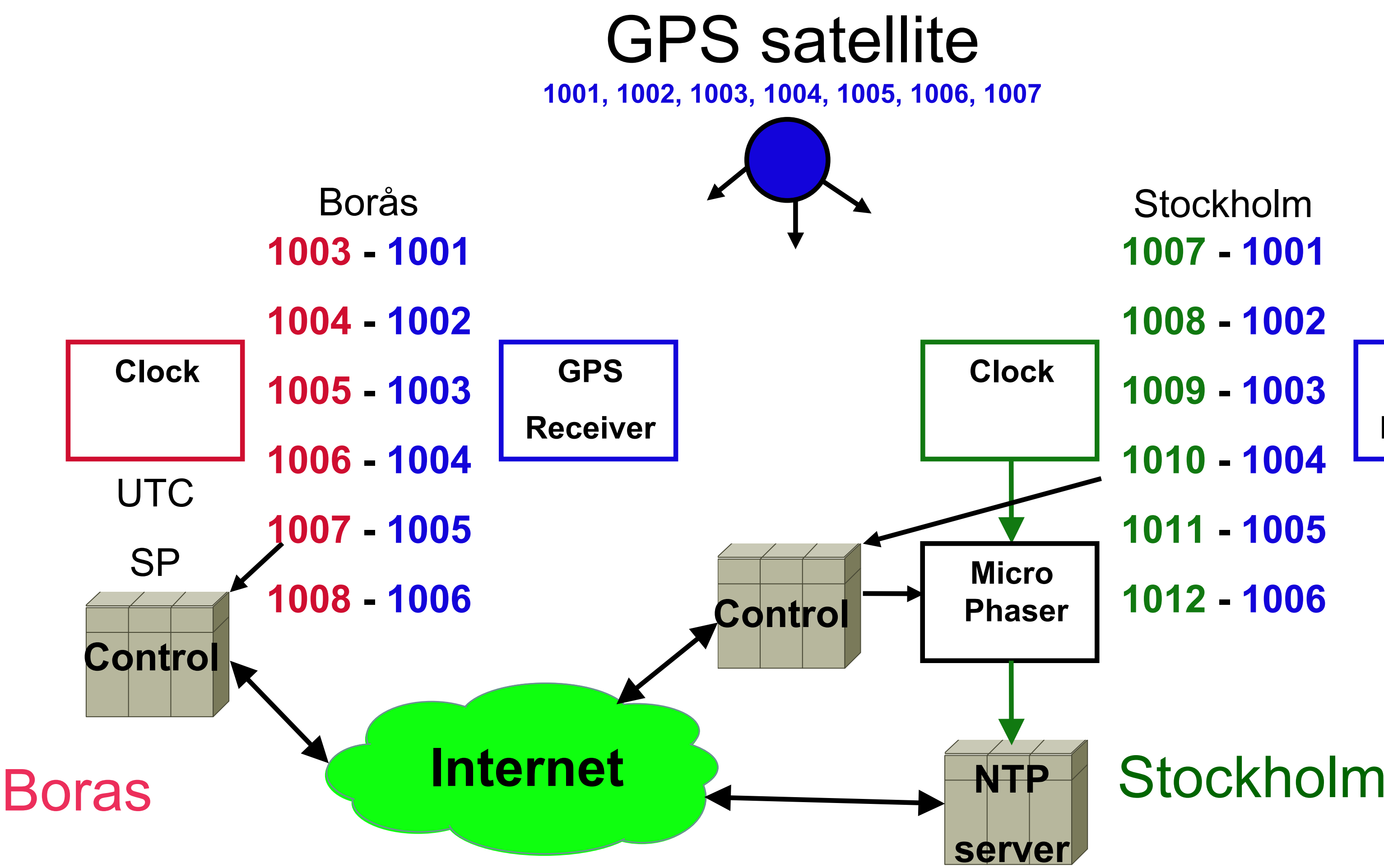
Methods for distributing and comparing time

- Satellites
  - Golobal Navigation Systems
    - GPS, GLONASS, Galileo,...
  - Geostationary communications satellites (TWSTFT)
- Ground based systems
  - Internet using NTP (Network Time Protocol)
  - Two Way over dedicated fiber
  - IEEE-1588 over dedicated networks
  - Radio Transmission (MSF, DCF77, WWW, etc)

Time Transfer GPS using CA-code



GPS Common View

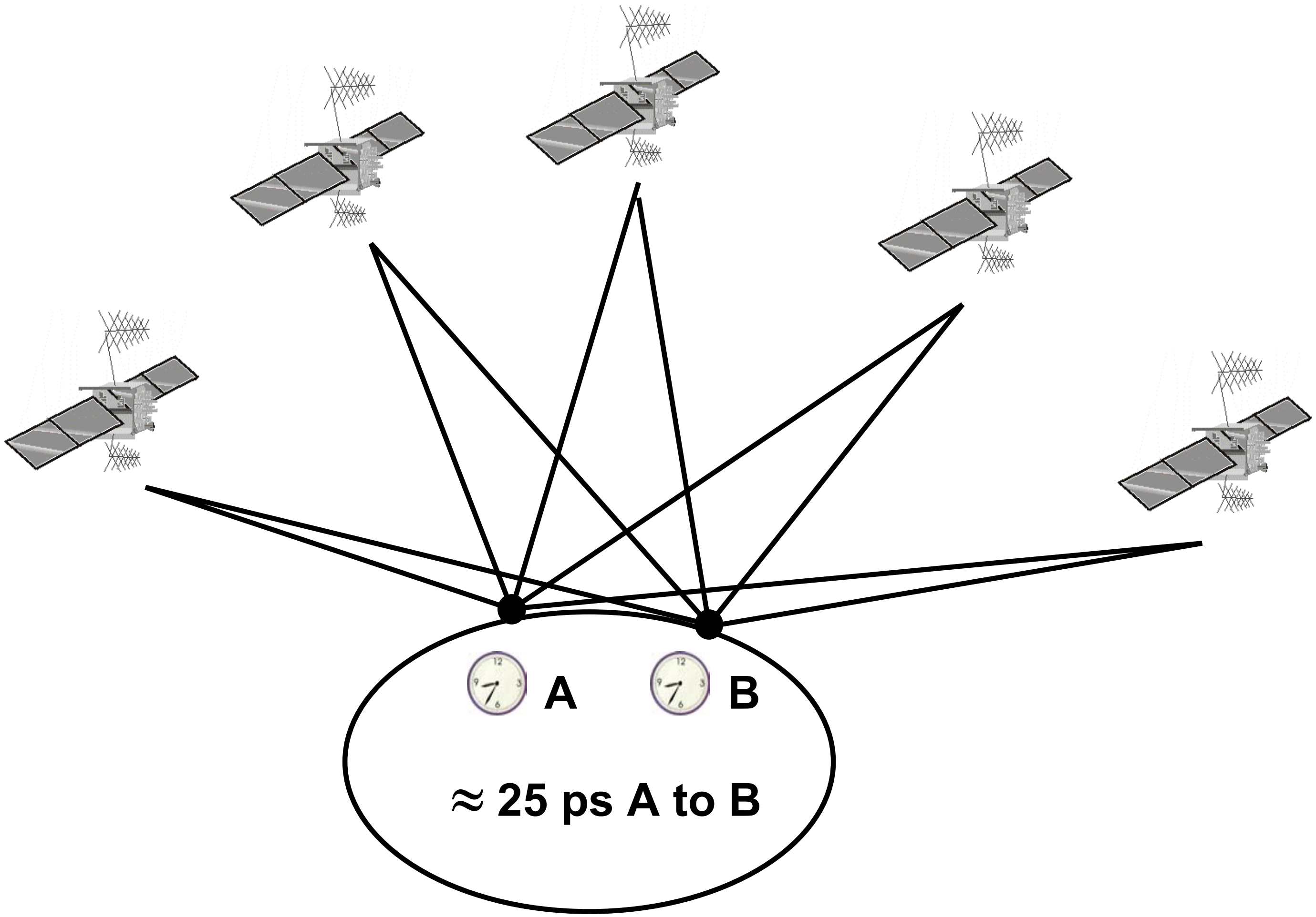


1005 UTC-SP = 1003 GPS

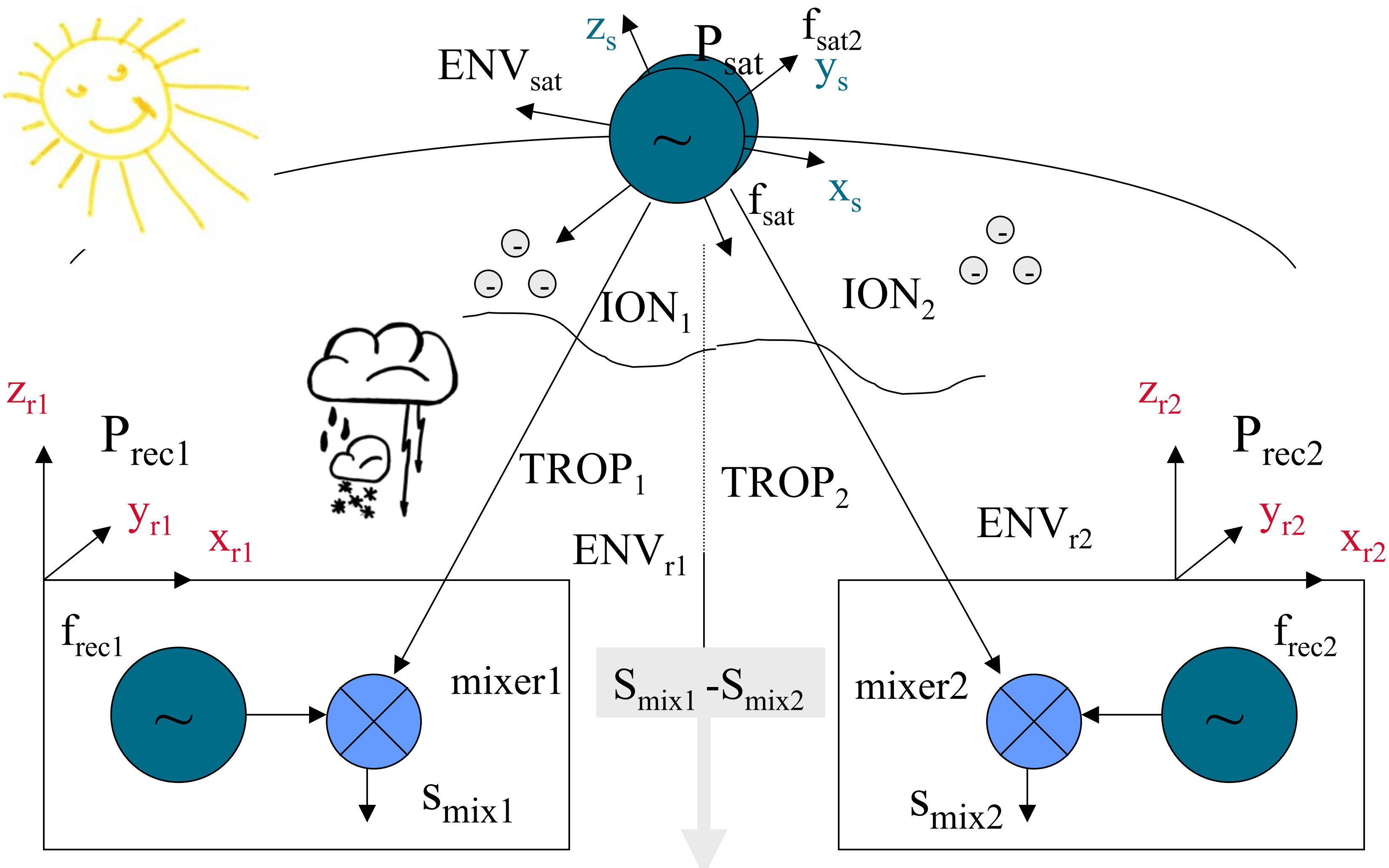
1009 Stockholm = 1003 GPS

SP -> Stockholm: “subtract 4”

Time transfer using GPS CV carrier/phase



Carrier Phase Common View GPS



$$S_{mix1} = \Delta(f_{rec1}, f_{sat}) + \Delta P_{sat} + \Delta P_{rec1} + \Delta ION_1 + \Delta TROP_1 + \Delta ENV_{r1} + \Delta ENV_s + \ldots + AMB_{r1/s}$$

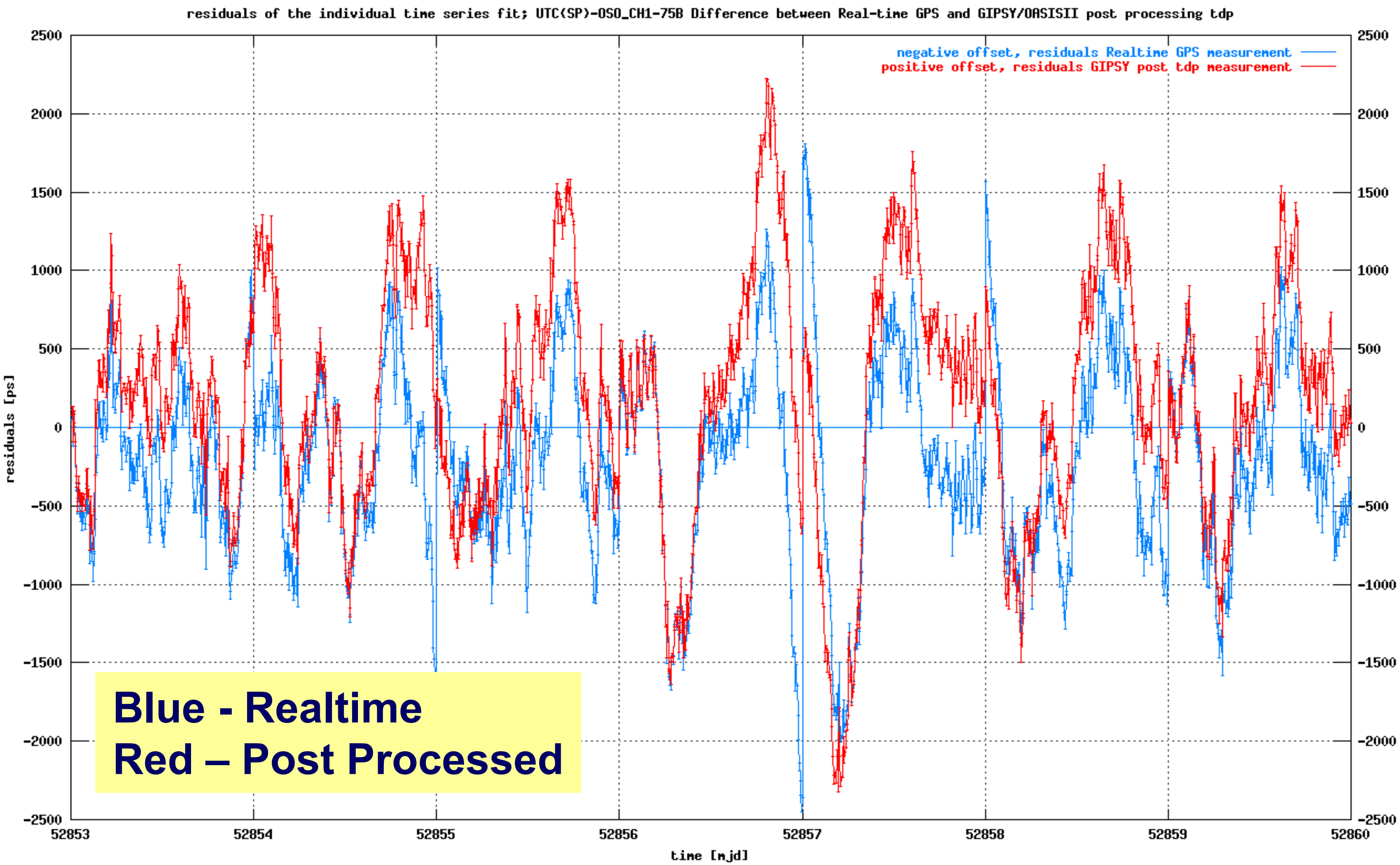
$$S_{mix2} = \Delta(f_{rec2}, f_{sat}) + \Delta P_{sat} + \Delta P_{rec2} + \Delta ION_2 + \Delta TROP_2 + \Delta ENV_{r2} + \Delta ENV_s + \ldots + AMB_{r2/s}$$

M CONST

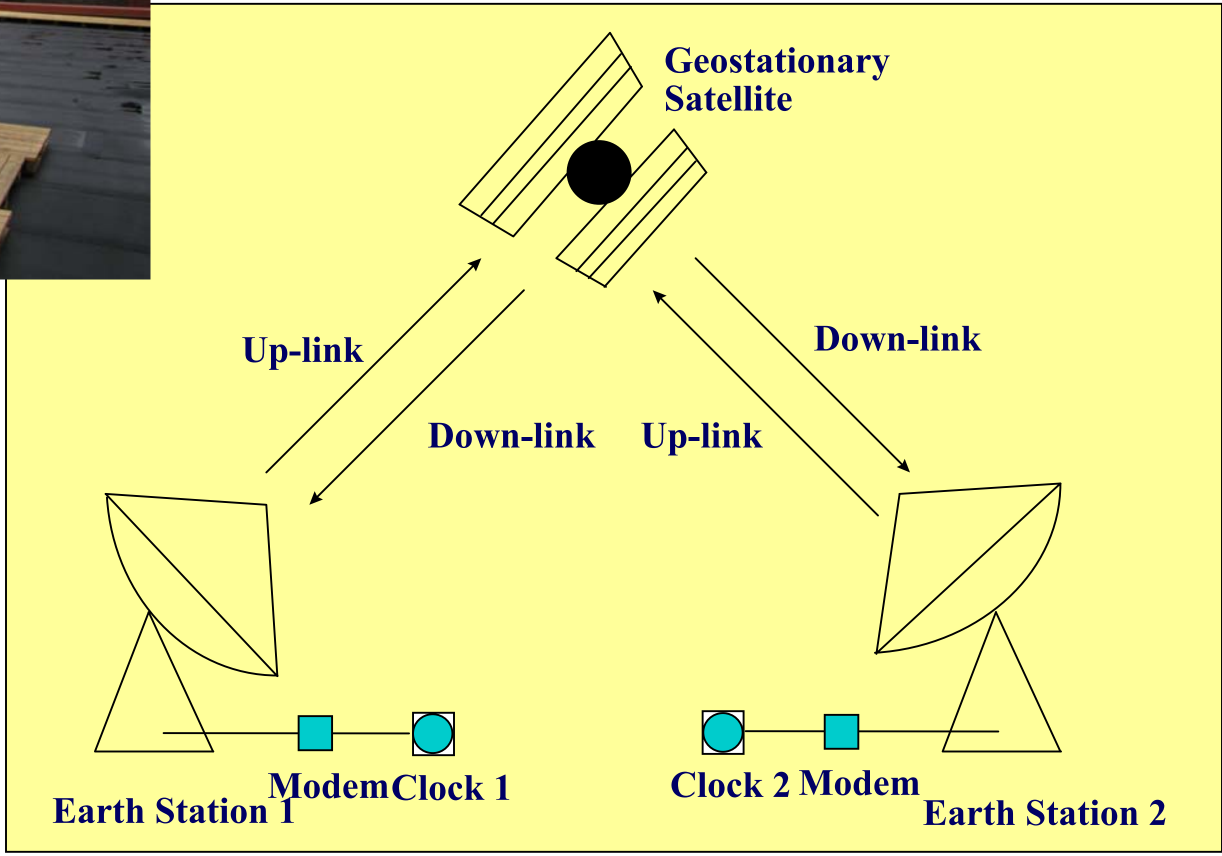
M CONST

Carrier Phase Common View

Comparison of SP CS and Onsala HM



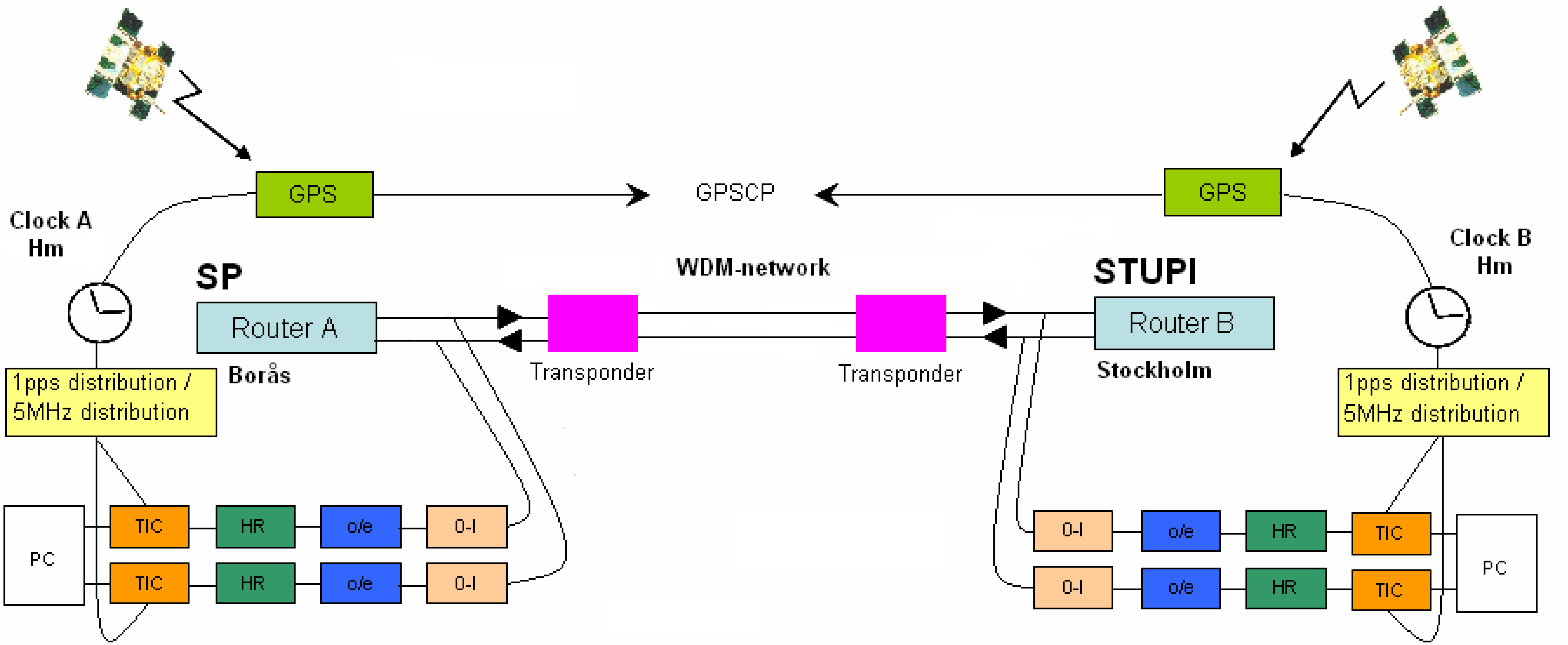
Two-Way Satellite Time and Frequency Transfer, TWSTFT



Two-Way Satellite Time and Frequency Transfer” (TWSTFT)

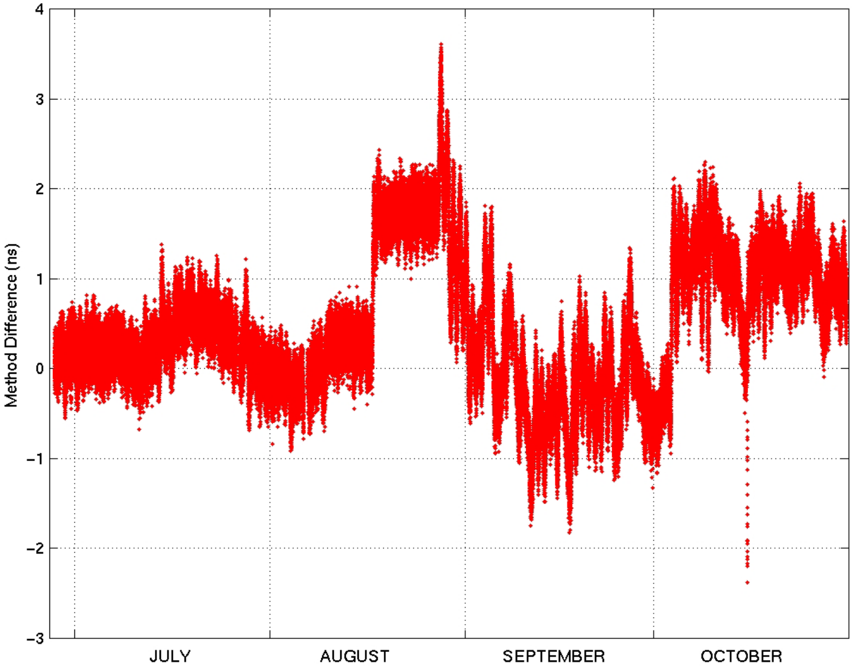
- Distribution of time between two stations using a geosyncronous communications satellite.
- Resolution is better than 1 ns
- Requres a dedicated transponder
- Independent complement to GPS
- Works on long distances where GNSS common view is not possible

Time transfer over fiber SP - STUPI:



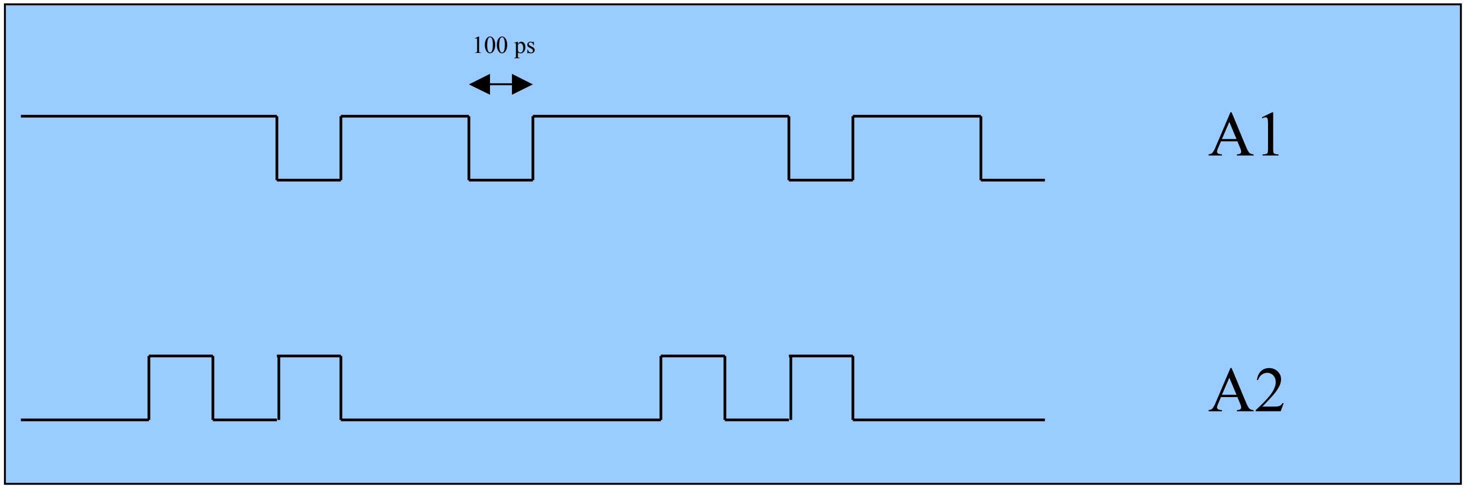
Measurements results

- **We have performed a time transfer experiment between two Hydrogen-masers separated by a distance of 563,261m using a typical transponder based OC192/STM64 D-WDM system. (POS framing)**
- **Results from time transfer experiment show precision compared to GPS carrier phase common view of < 1 ns**



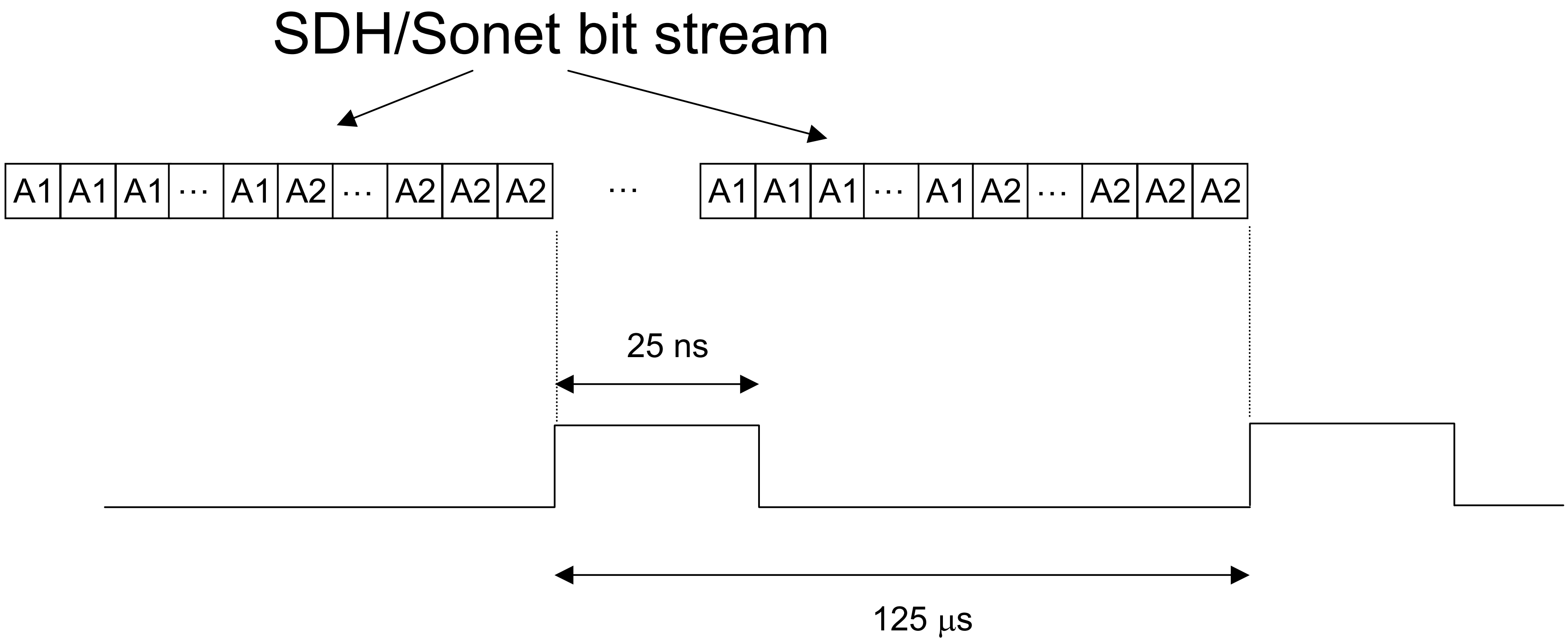
SDH / Sonet - Physical layer

- **Built on frames, each 125 μs long (nominal)**
- **Each frame consists of header and payload**
- **Each header starts with unique binary sequence (frame alignment bytes)**
  - In STM-64 (OC192) (10 Gbit/s):
    192 A1 bytes (11110110) followed by
    192 A2 bytes (00101000)

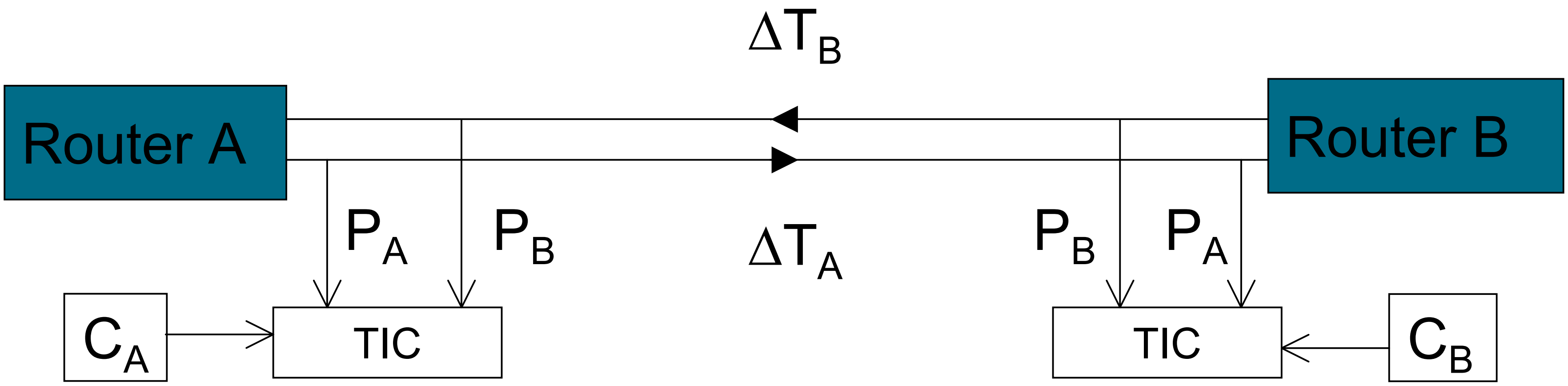


Pulse generation

- **Electrical pulse generated after each sequence of A1 and A2 bytes using "header recognizer"**



Two-Way Time transfer between A and B



$\Delta C_{AA} = C_A - P_A$

$\Delta C_{AB} = C_A - P_B + \Delta T_B$

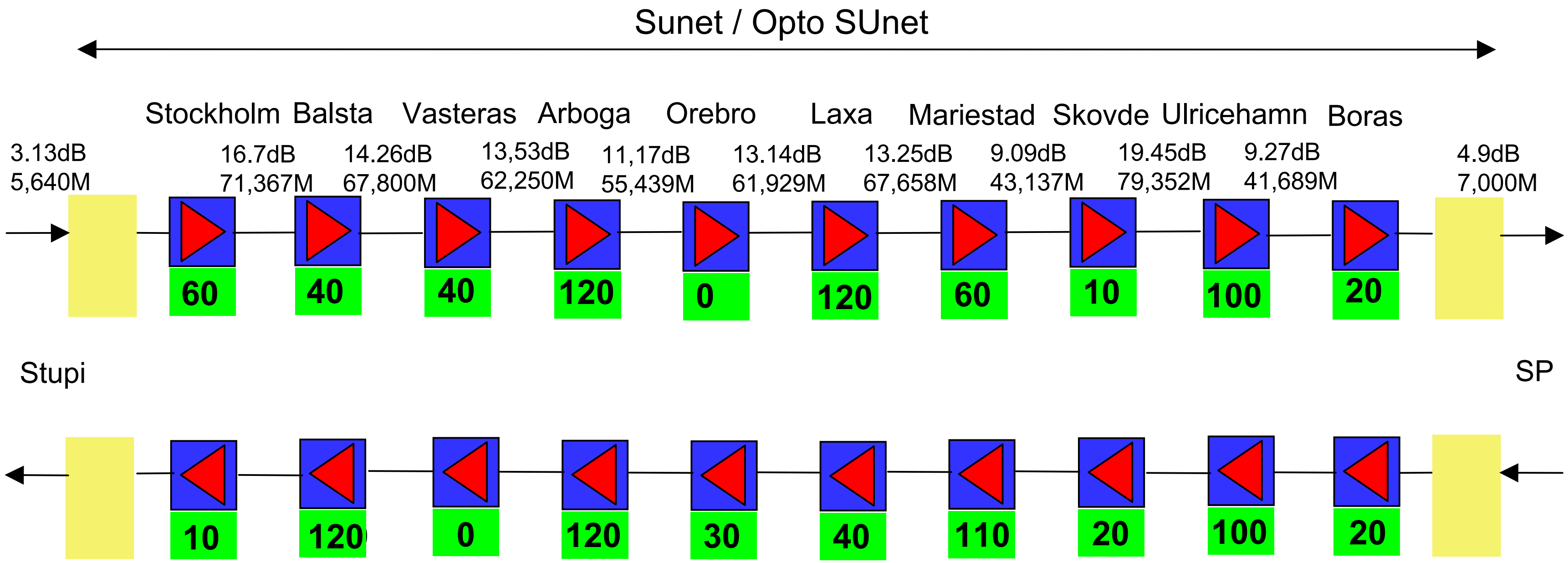
$\Delta C_{BA} = C_B - P_A + \Delta T_A$

$\Delta C_{BB} = C_B - P_B$

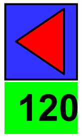
$$2(C_A - C_B) = (\Delta C_{AA} - \Delta C_{BA}) + (\Delta C_{AB} - \Delta C_{BB}) + F(t)$$

F(t) is differential path delay + local equipment delays

SP <=> STUPI fiber path



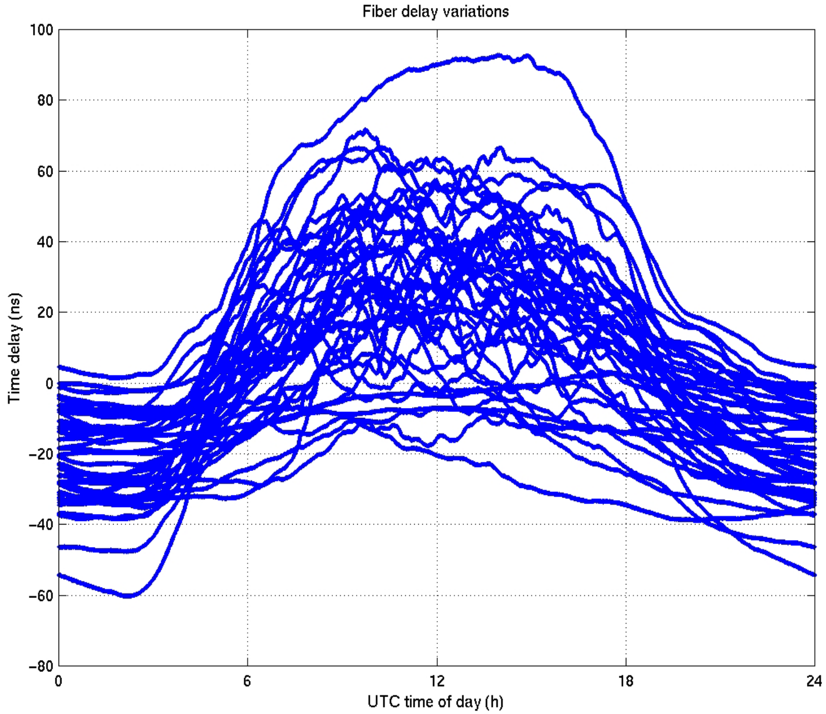
Ciena Corestream OC192/STM64 Transponder, Band 6, Chan 2



EDFA (Erbium Doped Fiber Amplifier)

Dispersion compensation fiber SMF28 equivalent length in amplifier mid stage

- **>500 km network distance between clocks located at SP (Borås) and STUPI (Stockholm)**

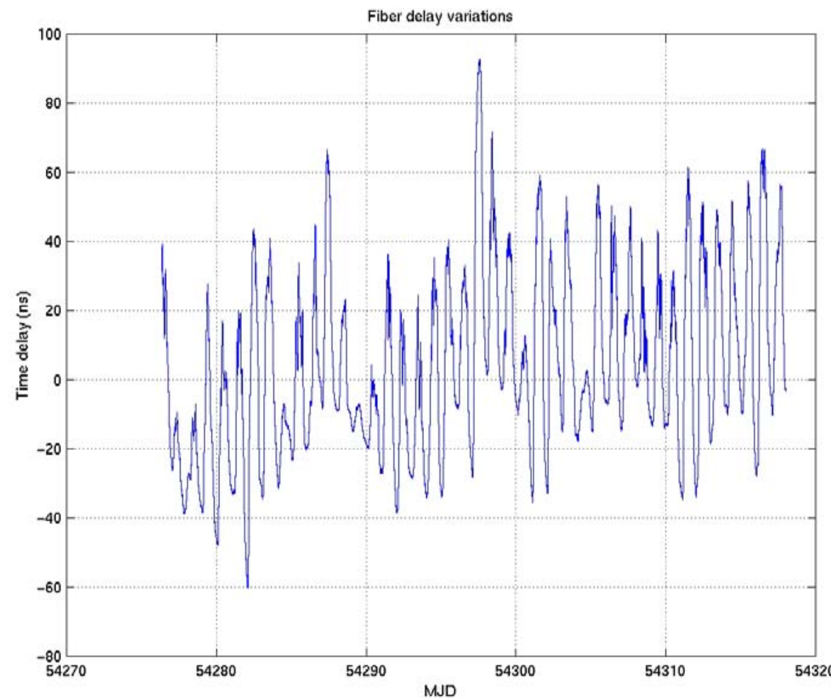


Fiber path delay variations

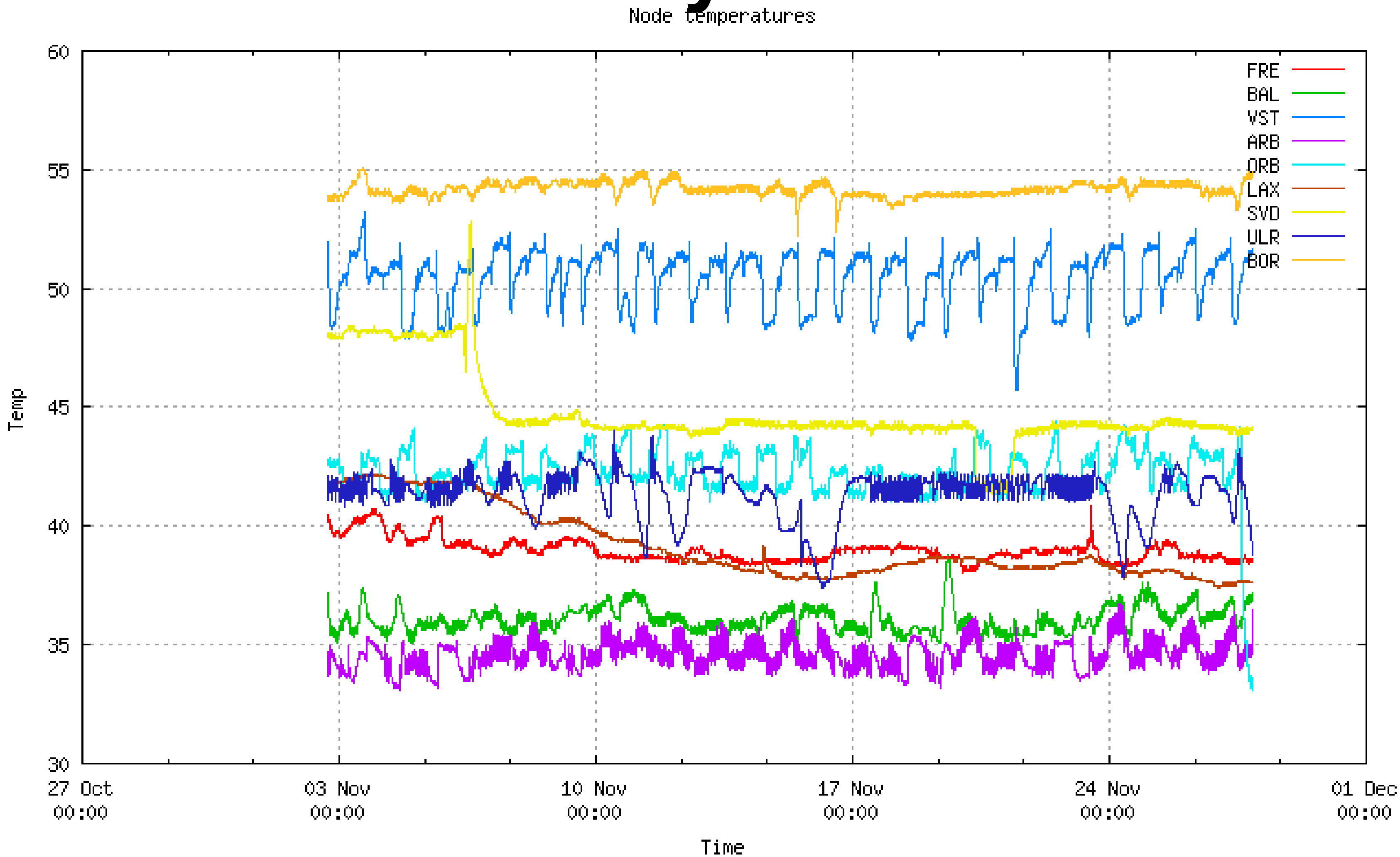
Fiber segments are a mix of both ground buried and Arial fiber (power line)

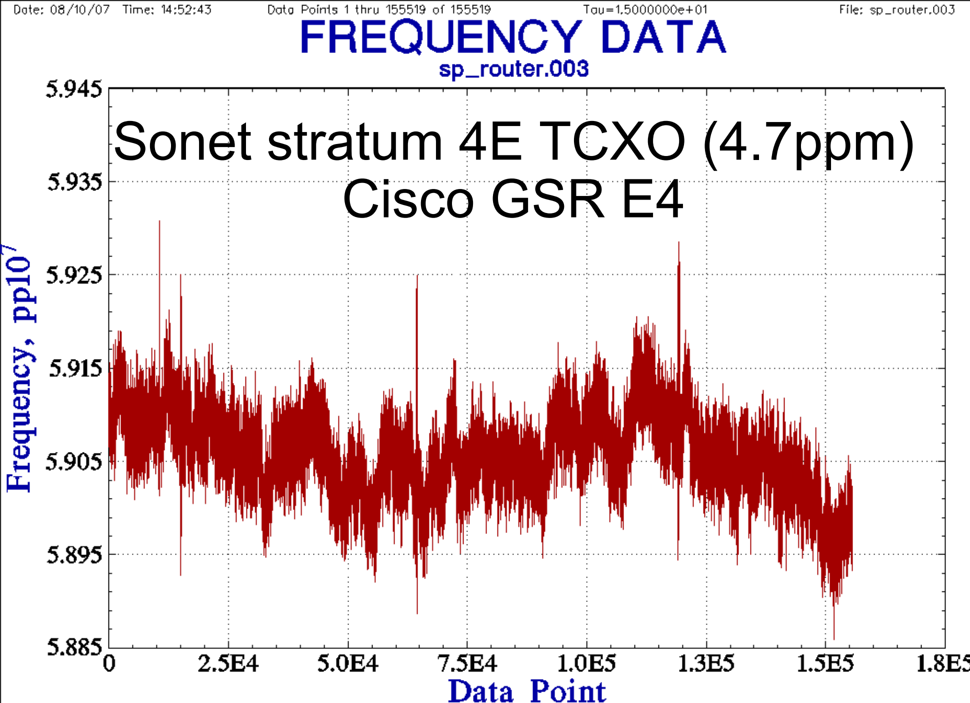
Total length 563,2611M (+dispersion compensation)

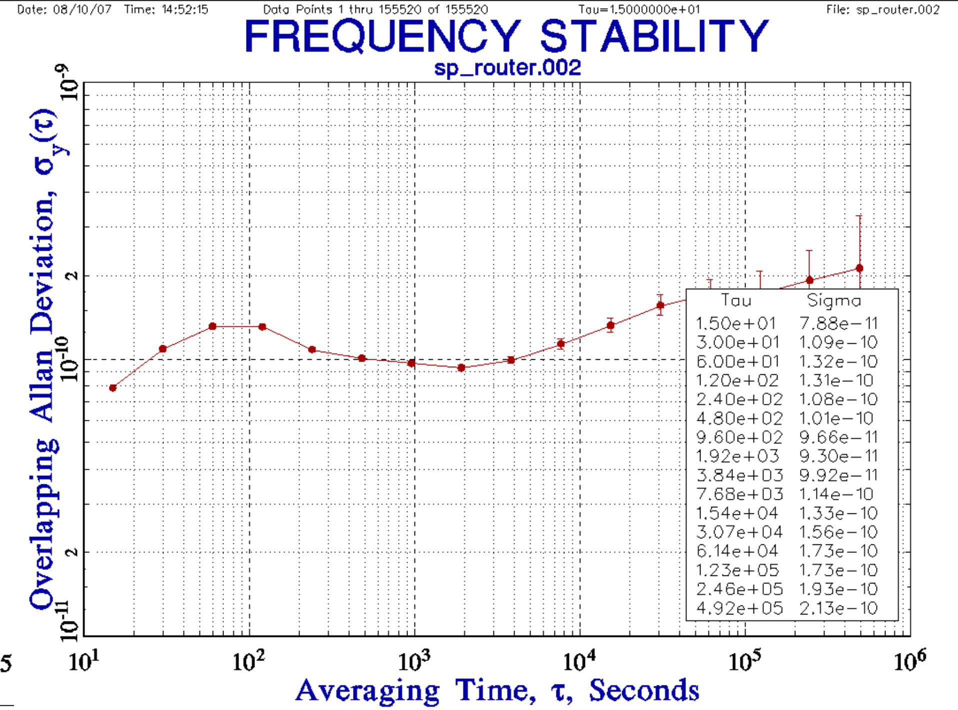
One way delay difference 150ns

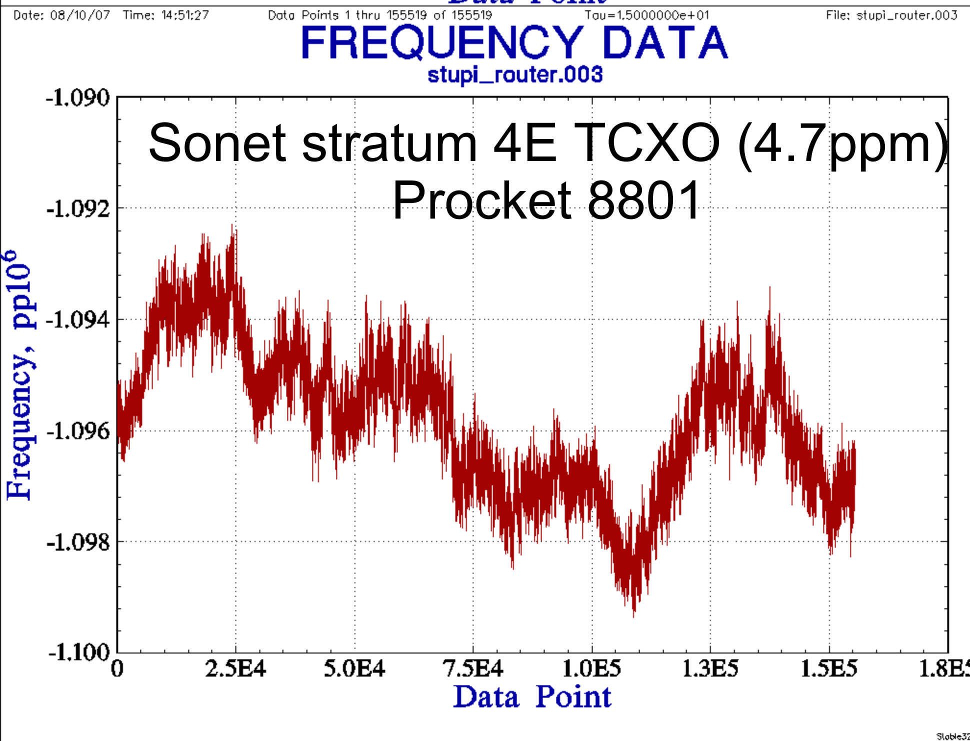


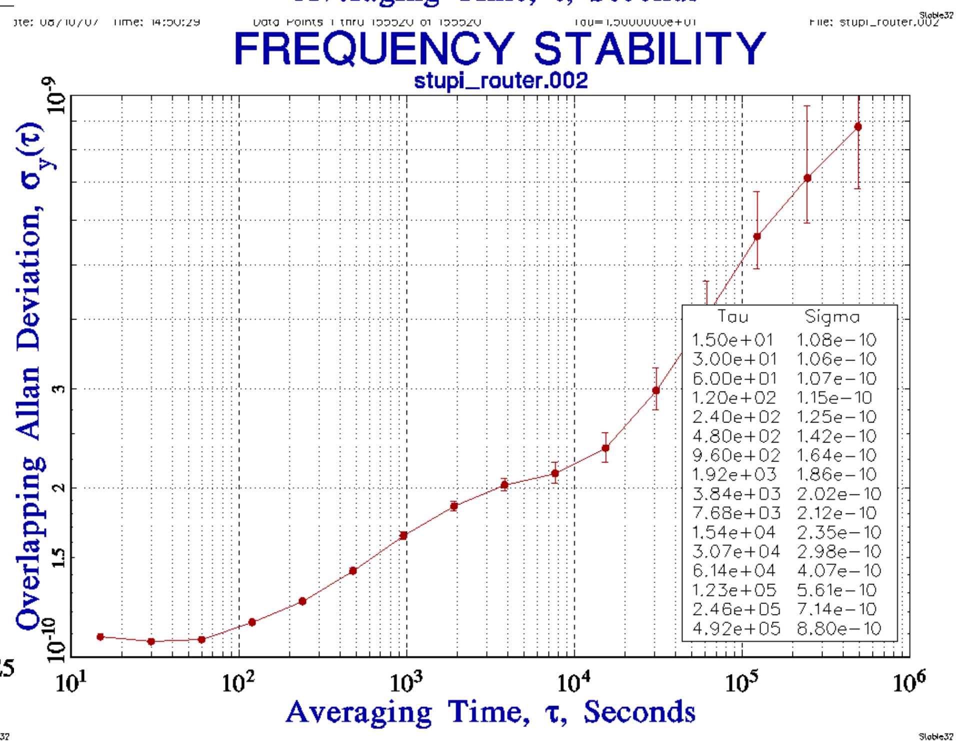
Temperature in amplifier power supply
22 day view



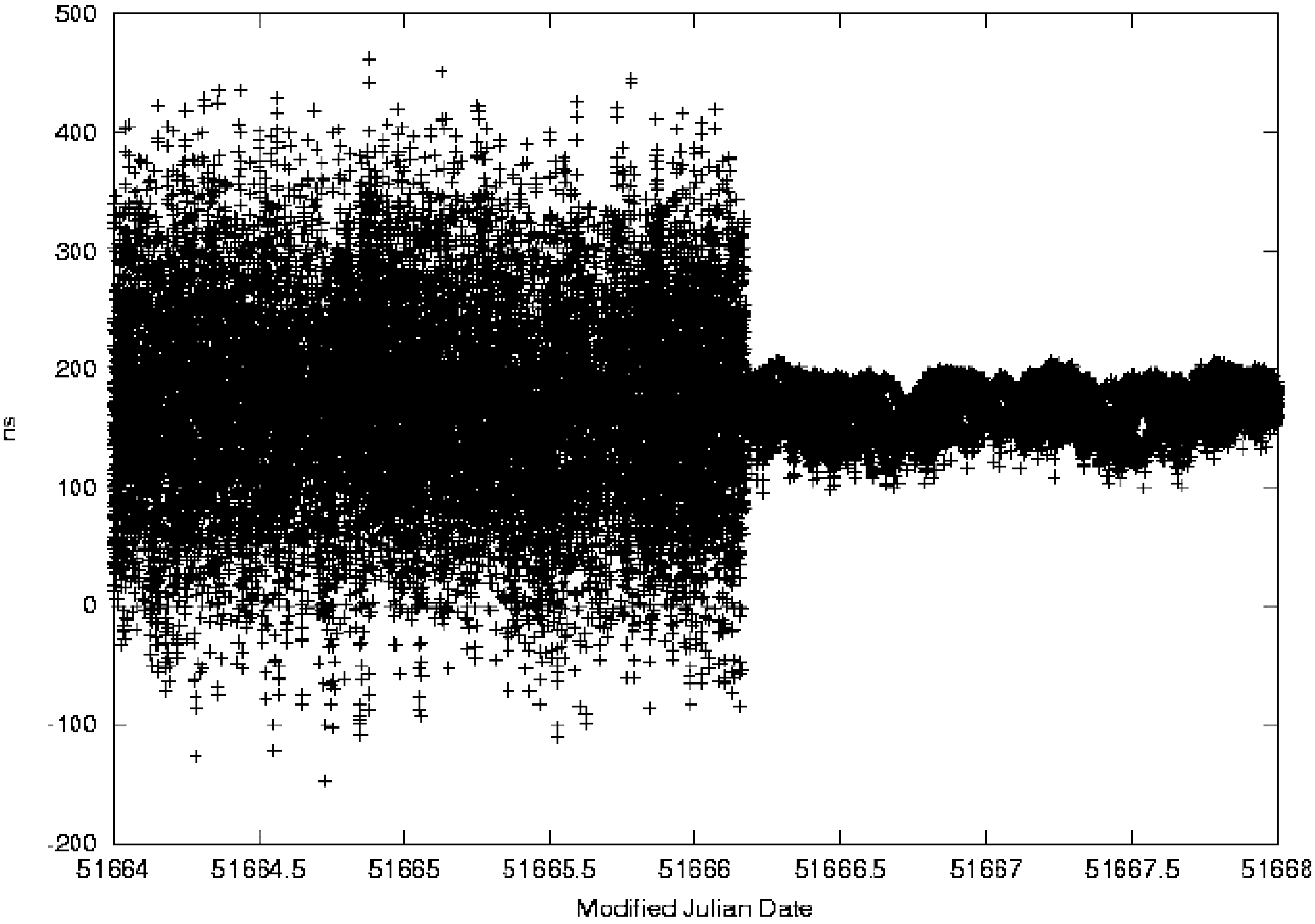

Date: 08/10/07 Time: 14:52:43 Data Points 1 thru 155519 of 155519 Tau=1.5000000e+01 File: sp_router.003
FREQUENCY DATA
sp_router.003
Sonet stratum 4E TCXO (4.7ppm)
Cisco GSR E4
Frequency, pp10^7
Data Point
5.945
5.935
5.925
5.915
5.905
5.895
5.885
0
2.5E4
5.0E4
7.5E4
1.0E5
1.3E5
1.5E5
1.8E5


Date: 08/10/07 Time: 14:52:15 Data Points 1 thru 155520 of 155520 Tau=1.5000000e+01 File: sp_router.002
FREQUENCY STABILITY
sp_router.002
Overlapping Allan Deviation, σy(τ)
Averaging Time, τ, Seconds
Tau Sigma
1.50e+01 7.88e-11
3.00e+01 1.09e-10
6.00e+01 1.32e-10
1.20e+02 1.31e-10
2.40e+02 1.08e-10
4.80e+02 1.01e-10
9.60e+02 9.66e-11
1.92e+03 9.30e-11
3.84e+03 9.92e-11
7.68e+03 1.14e-10
1.54e+04 1.33e-10
3.07e+04 1.56e-10
6.14e+04 1.73e-10
1.23e+05 1.73e-10
2.46e+05 1.93e-10
4.92e+05 2.13e-10

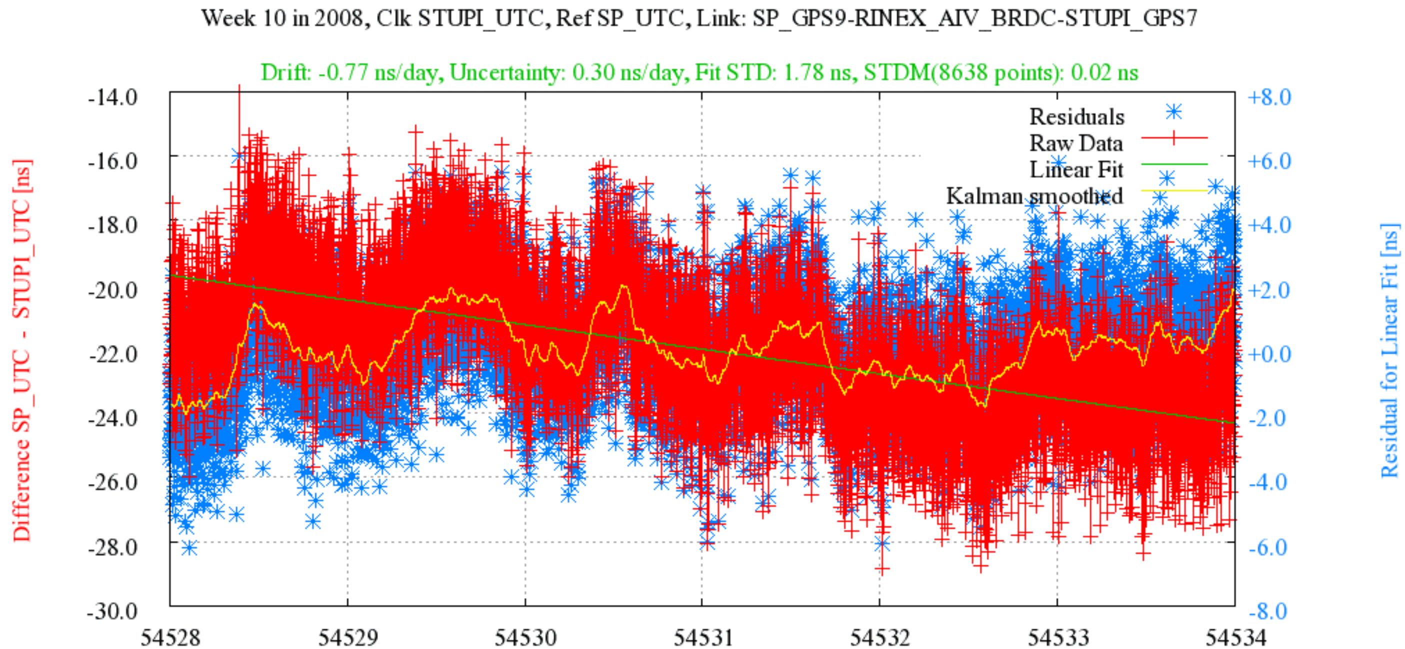

Date: 08/10/07 Time: 14:51:27 Data Points 1 thru 155519 of 155519 Tau=1.5000000e+01 File: stupi_router.003
FREQUENCY DATA
stupi_router.003
Sonet stratum 4E TCXO (4.7ppm)
Procket 8801
Frequency, pp10^6
Data Point
-1.090
-1.092
-1.094
-1.096
-1.098
-1.100
0
2.5E4
5.0E4
7.5E4
1.0E5
1.3E5
1.5E5
1.8E5


FREQUENCY STABILITY
stupi_router.002
Overlapping Allan Deviation, σy(τ)
Averaging Time, τ, Seconds
Tau Sigma
1.50e+01 1.08e-10
3.00e+01 1.06e-10
6.00e+01 1.07e-10
1.20e+02 1.15e-10
2.40e+02 1.25e-10
4.80e+02 1.42e-10
9.60e+02 1.64e-10
1.92e+03 1.86e-10
3.84e+03 2.02e-10
7.68e+03 2.12e-10
1.54e+04 2.35e-10
3.07e+04 2.98e-10
6.14e+04 4.07e-10
1.23e+05 5.61e-10
2.46e+05 7.14e-10
4.92e+05 8.80e-10

Selective Availability turned off 2 May, 2000

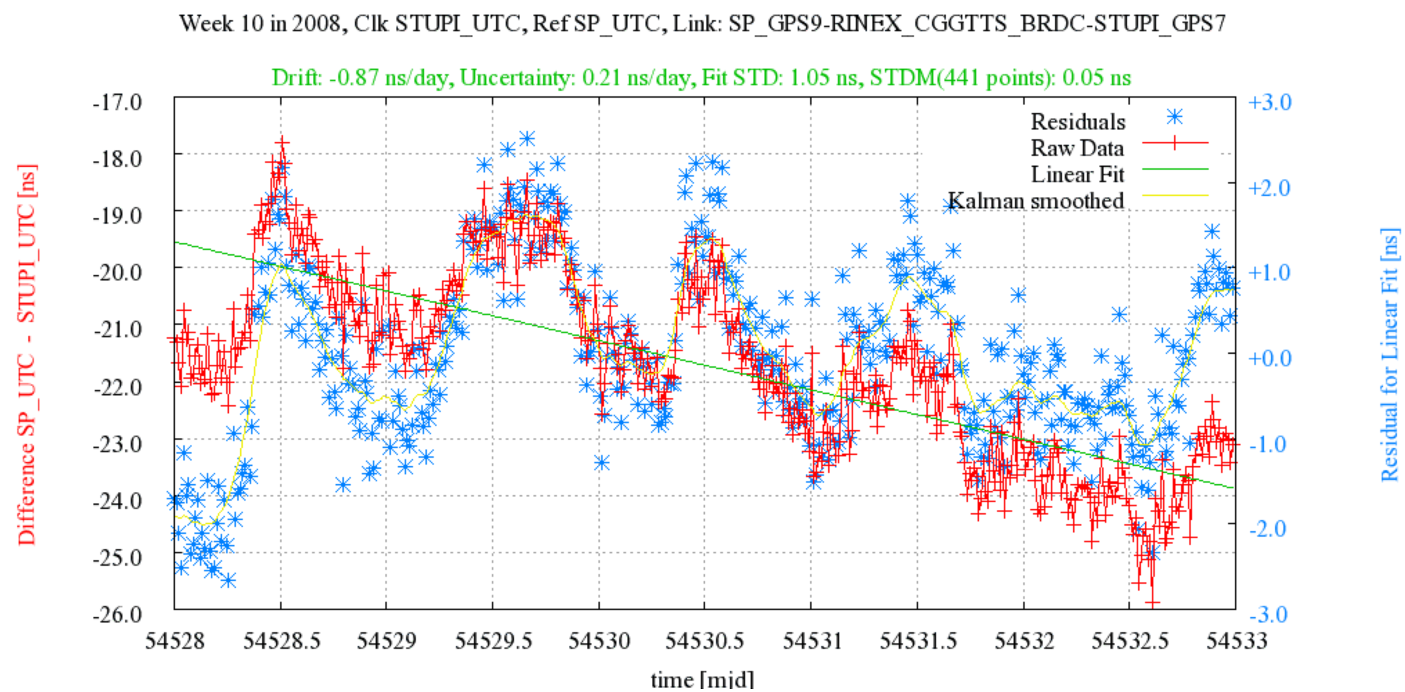


Raw Carrier Phase Common View GPS



<4 ns error due to weather

Corrected Carrier Phase Common View GPS using IGS data



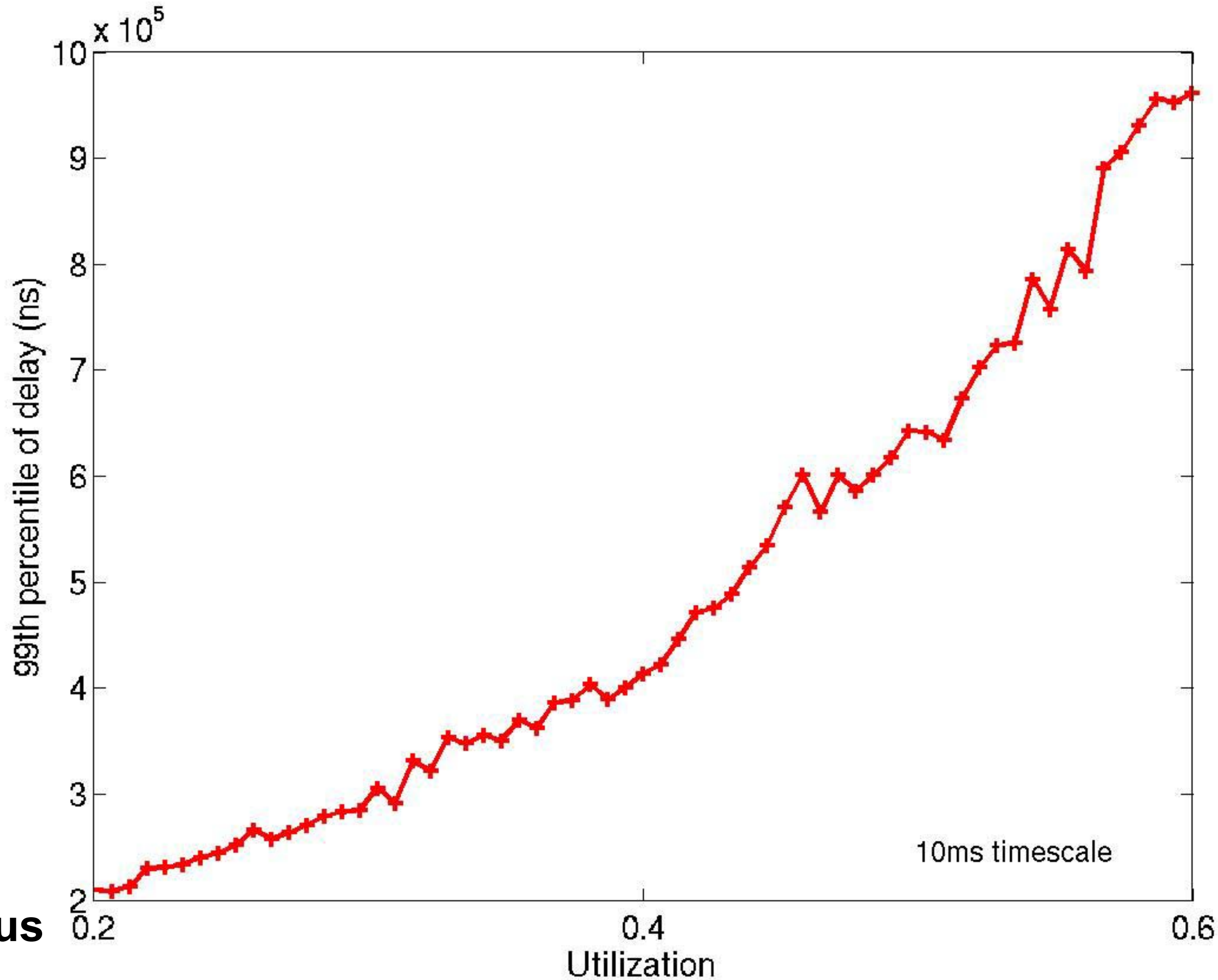
Difference between UTC and UTC(k)

MJD	USNO	GPS	NIST	PTB	SU	NPL	SP
	US	US	US	DE	SU	UK	SE
54404	0.0	-6.13	5.8	20.2	8.6	32.8	11.4
54409	0.0	-2.65	5.8	14.9	11.1	31.7	10.3
54414	0.0	-4.61	6.6	12.7	9.0	28.2	3.1
54419	-0.6	-7.47	5.6	10.5	7.3	25.8	0.5
54424	-1.1	-6.16	6.3	7.5	8.3	21.7	1.6
54429	-0.1	-4.82	7.1	3.9	6.2	16.6	4.3
54434	-0.3	-6.86	6.2	5.2	0.0	13.6	7.0
54439	-0.4	-5.98	5.1	4.3	0.1	9.6	7.8
54444	1.1	-2.22	4.9	0.8	2.6	4.2	10.0
54449	1.5	-4.81	5.2	0.0	4.7	0.0	8.2
54454	0.5	-2.97	3.3	4.4	3.9	3.5	7.4
54459	0.1	-5.17	3.0	6.5	4.4	7.9	4.7
54464	-0.3	-2.67	0.9	6.7	2.6	9.8	7.9
54469	-0.1	-4.07	1.3	6.4	3.4	8.2	6.6
54474	0.3	-3.96	0.6	8.7	3.4	39.2	14.9
54479	0.0	-3.76	0.9	10.2	3.2	13.1	11.7
54484	0.1	-5.48	1.9	13.1	4.6	15.1	16.8
54489	0.3	-0.33	1.2	20.3	3.1	22.6	20.2
54494	0.0	-5.49	2.3	16.6	3.9	32.9	23.9
54499	0.8	-5.82	3.8	10.8	6.8	36.2	26.1
54504	1.7	-2.18	2.9	8.8	6.3	33.3	31.2
54509	0.2	-3.14	5.1	5.7	1.9	35.4	32.3
54514	1.6	-1.74	5.3	13.2	2.4	27.6	26.7
54519	0.4	-7.22	6.7	15.8	2.2	20.1	22.4
54524	0.5	-5.42	8.4	11.4	1.4	13.5	17.1

(UTC-GPS= UTC(USNO)-GPS) **Source BIPM Circular-T and USNO**

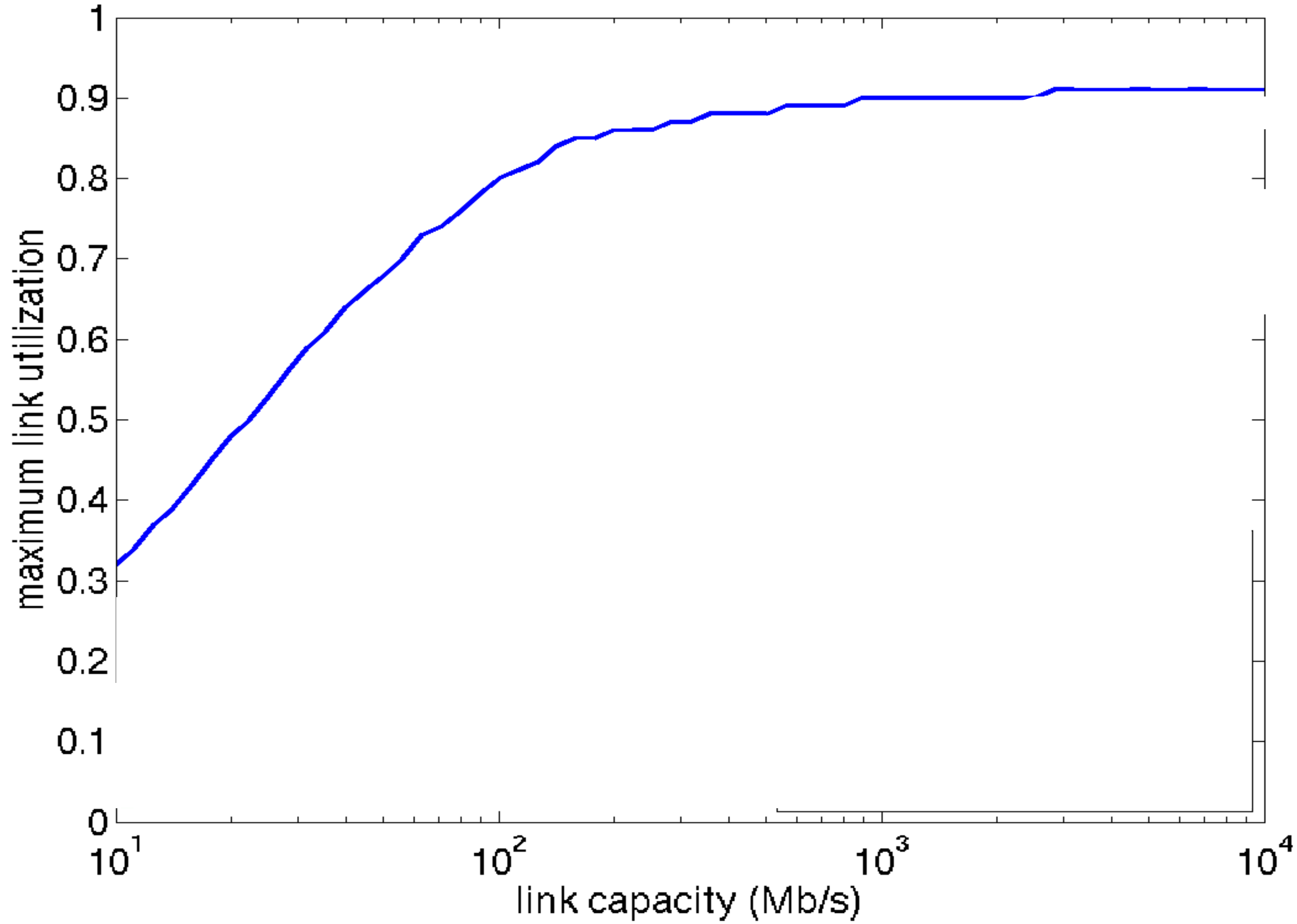
Delay vs. Link utilization OC12 (622Mbit)

1ms

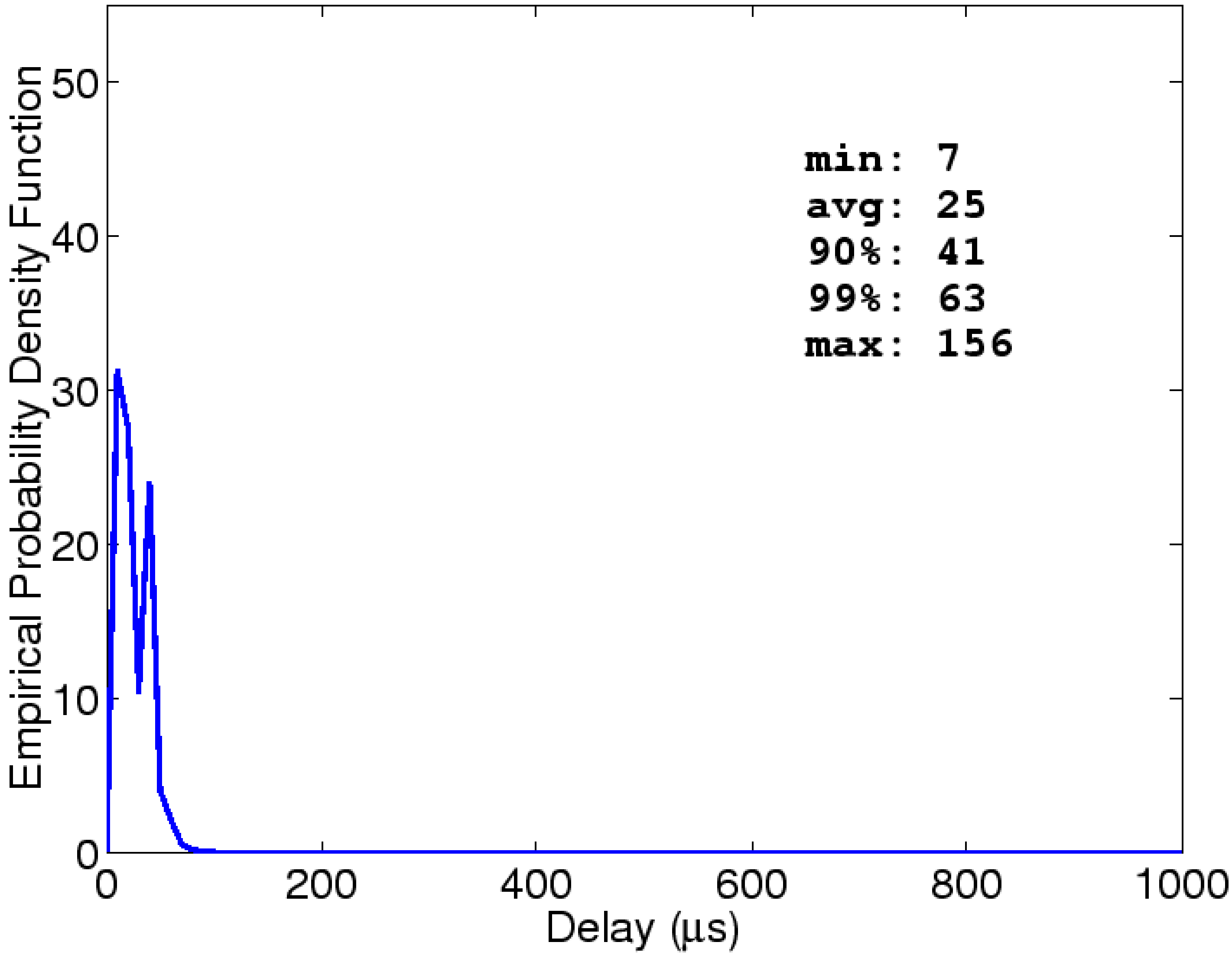


200us

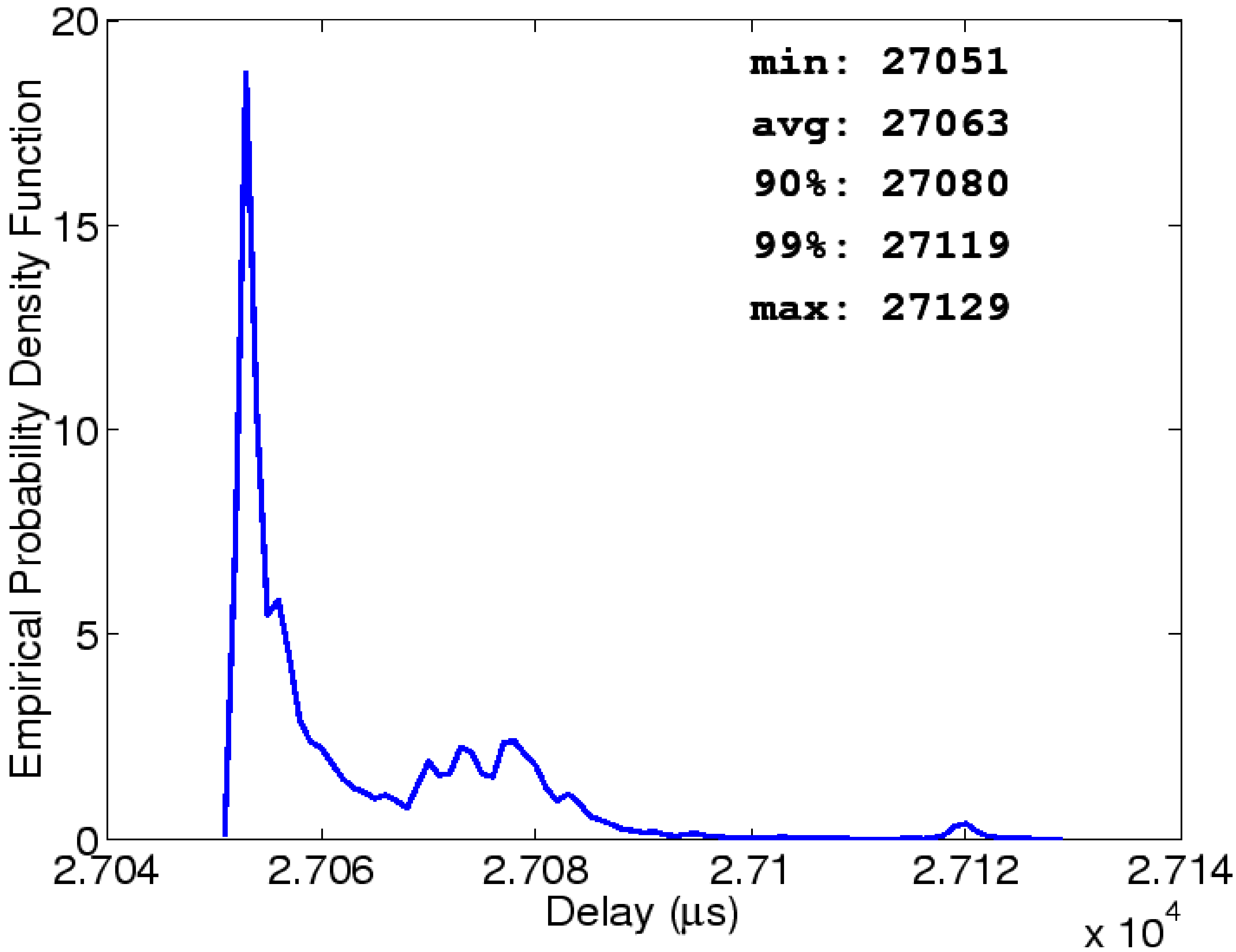
Queuing delay in a router



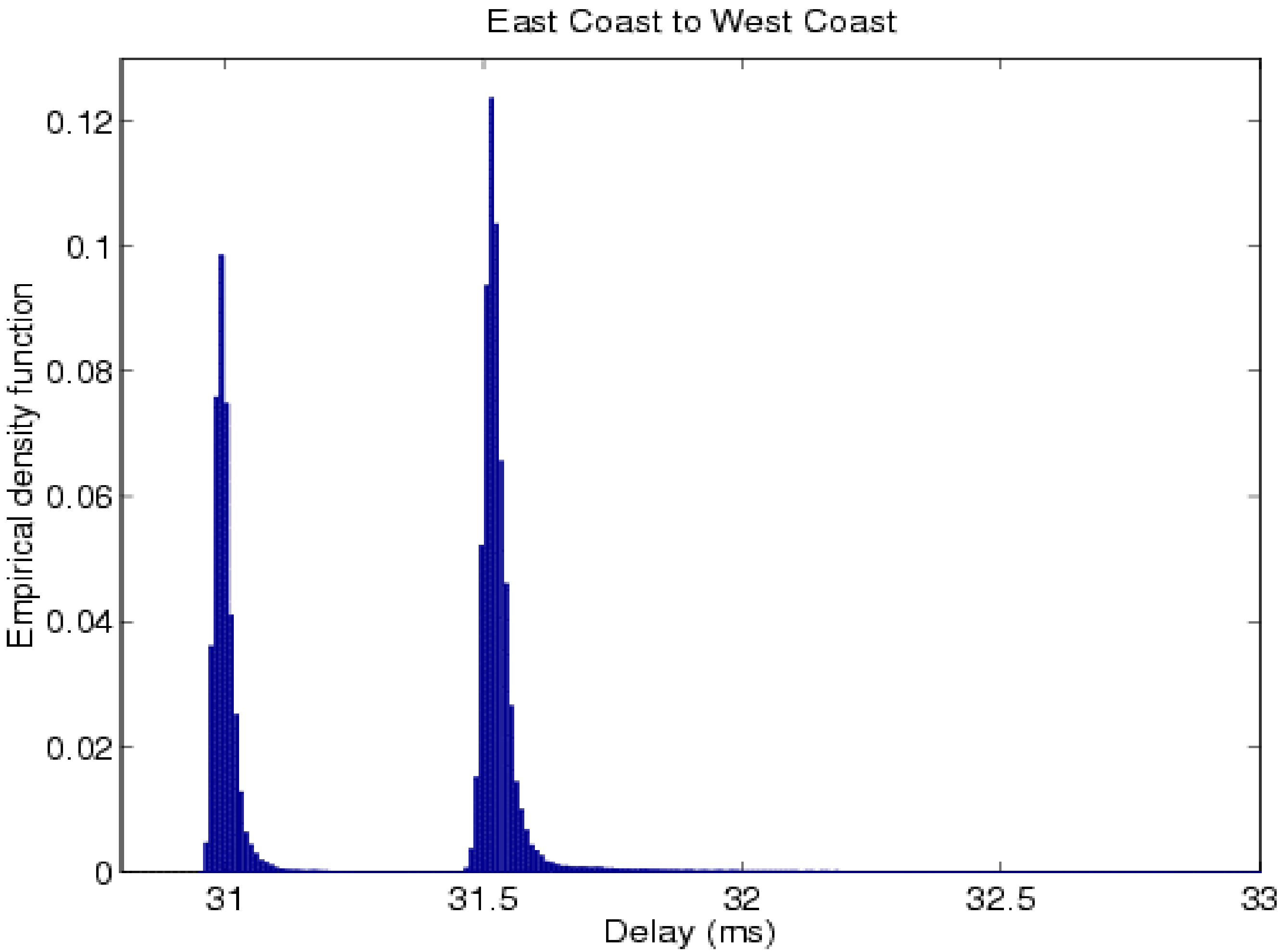
Delay through a router OC-12



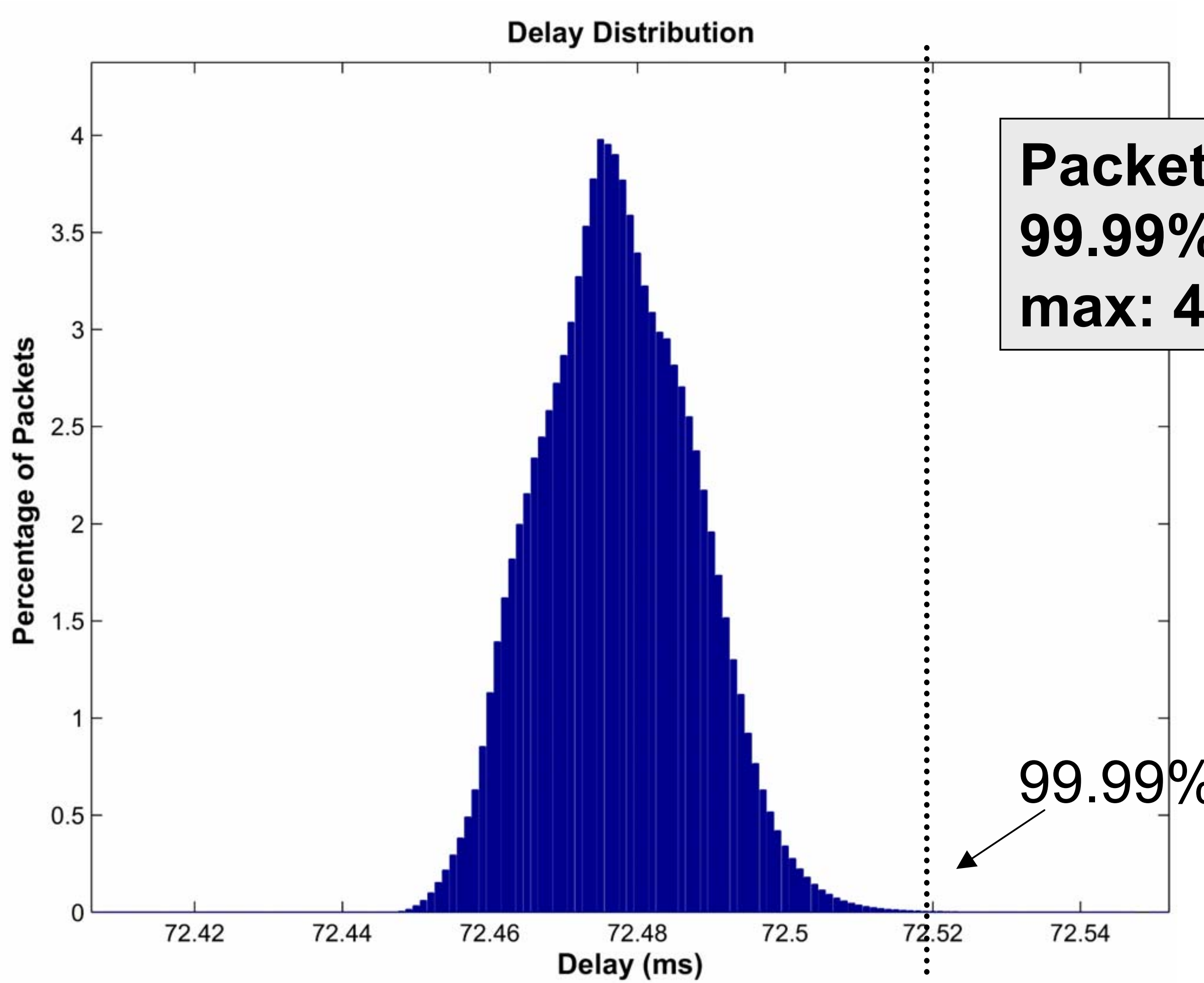
POP to POP delay (Philadelphia-San Jose)



POP to POP delay (San Francisco-Reston)

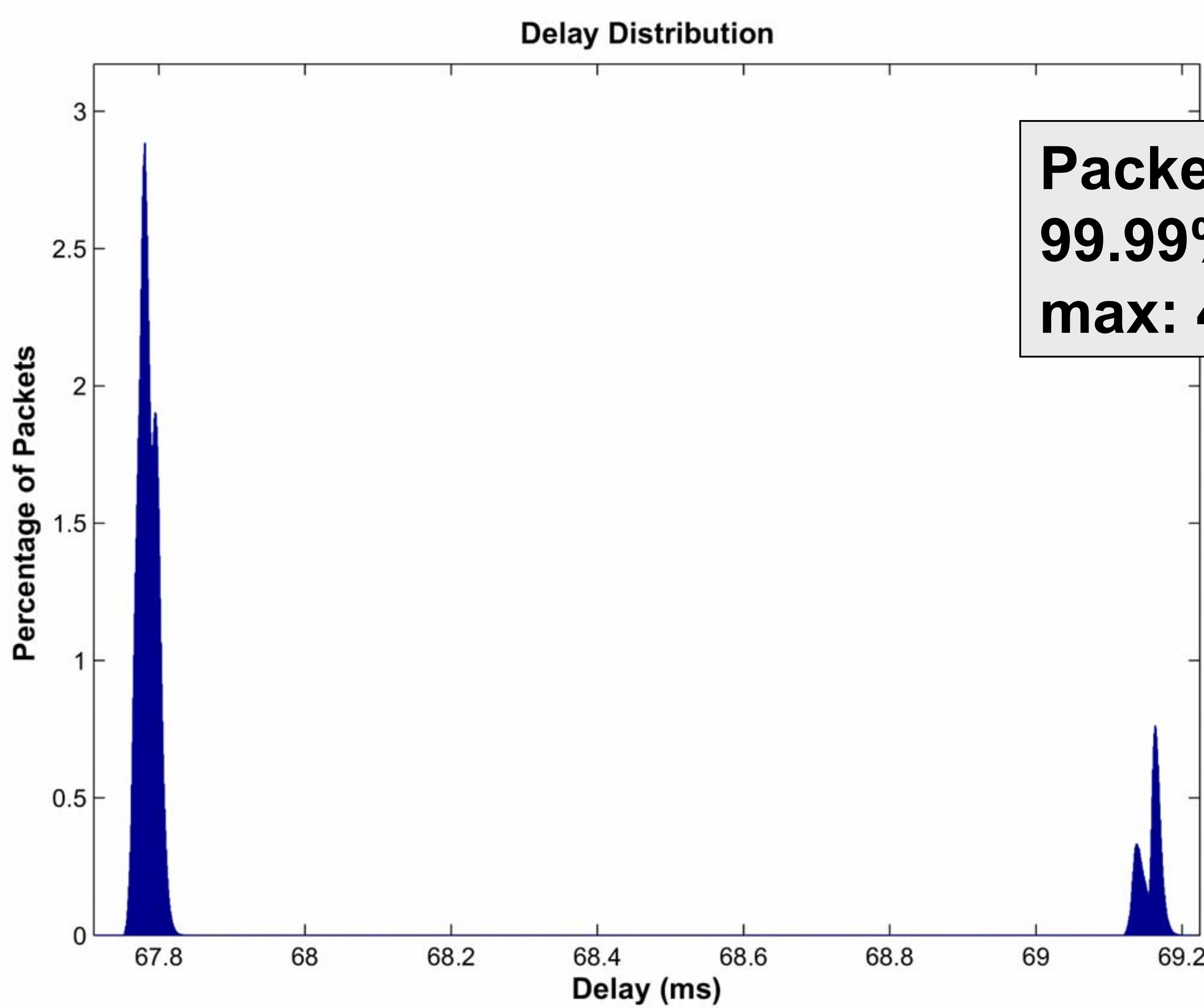


One way delay: Paris – San Jose



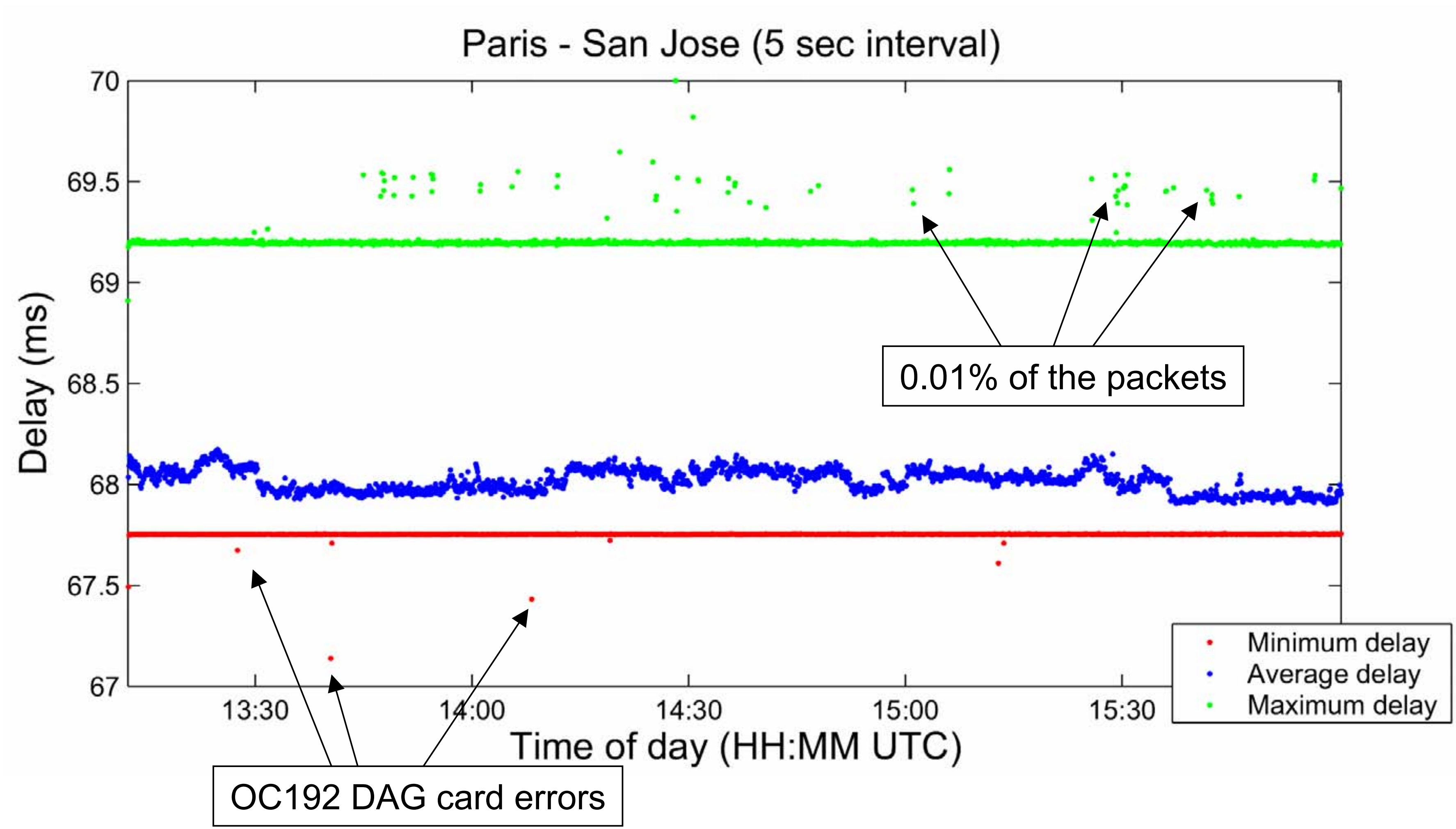
Packets: 76M
99.99%: 72.52ms
max: 488.61 ms

One way delay: Paris – San Jose



Packets: 16M
99.99%: 69.20 ms
max: 443.96 ms

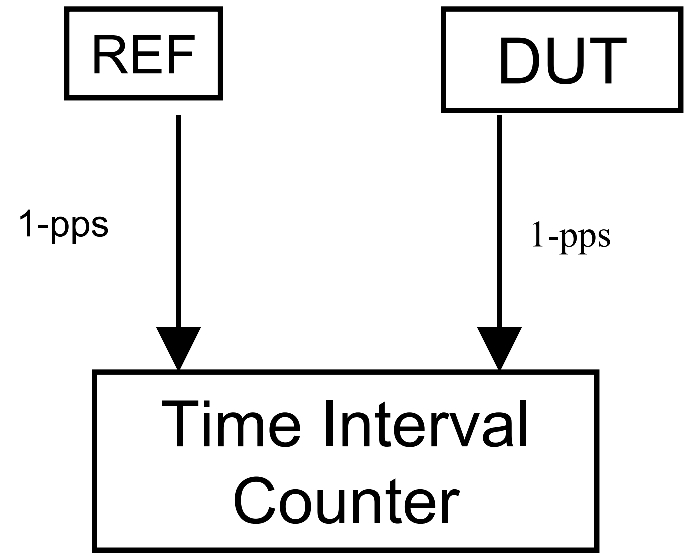
One way delay over time



Characteristics of different Oshillators

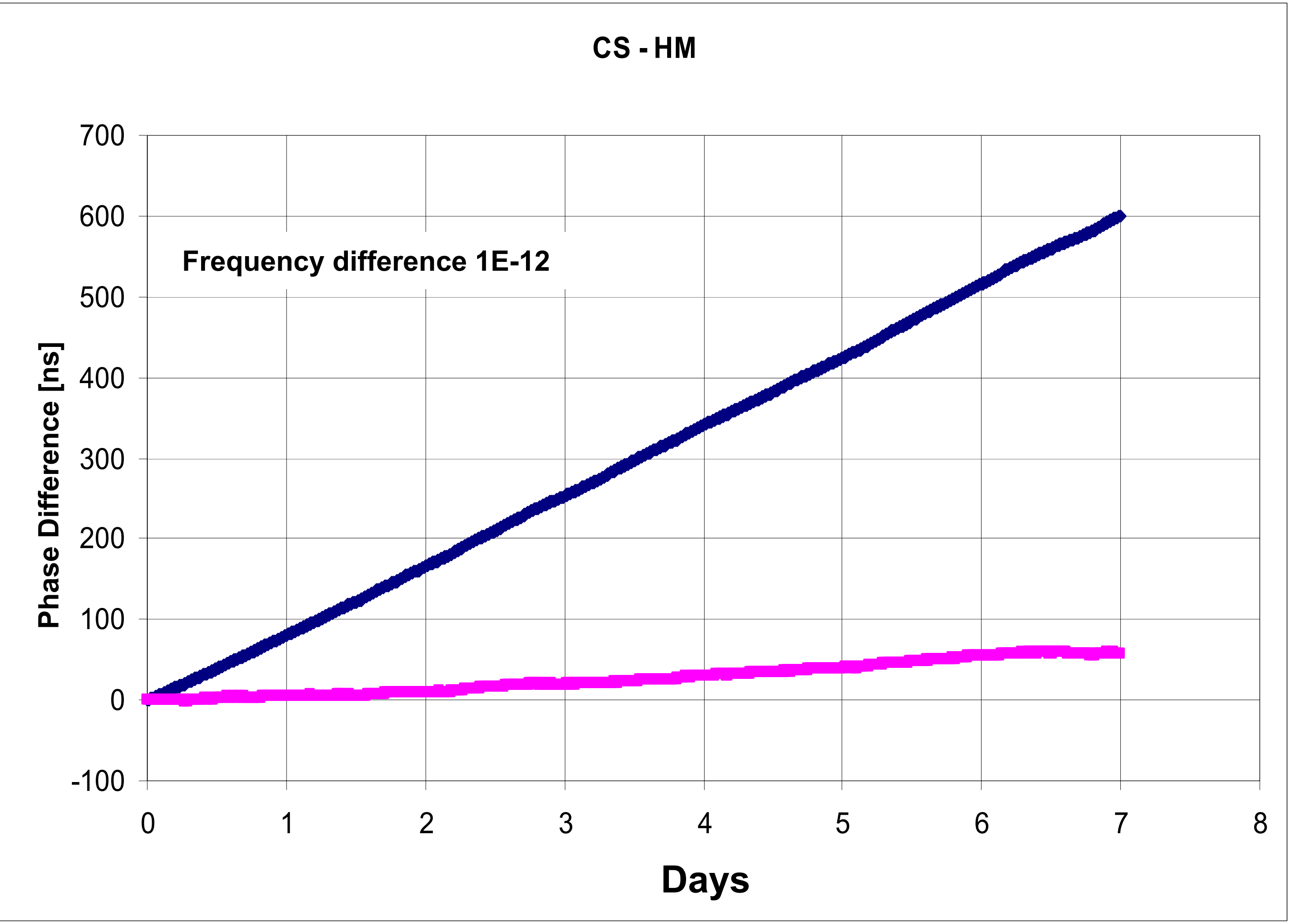
- **Atomic clocks**
  - –**Cesium**
  - –**Hydrogen**
  - –**Rubidium**
- **Quartz**

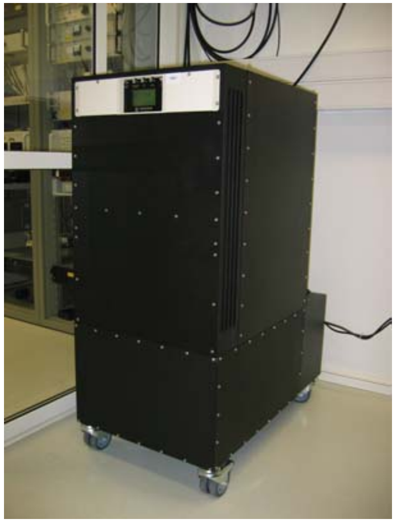
Mesurement setup



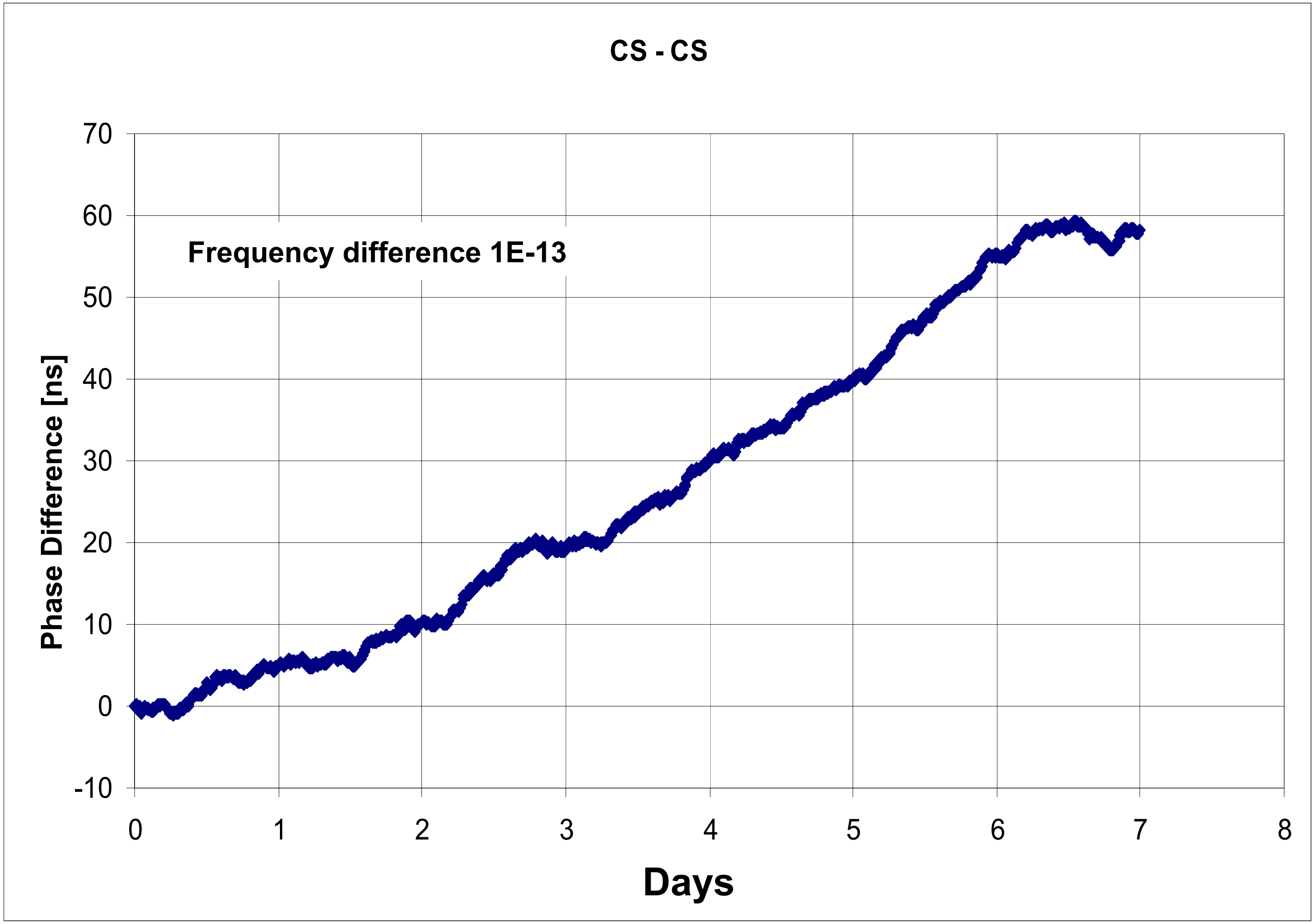
$$\text{Frequency Differance: } \Delta f = \frac{\Delta t_i - \Delta t_{i-T}}{T}$$

Cesium – Hydrogen



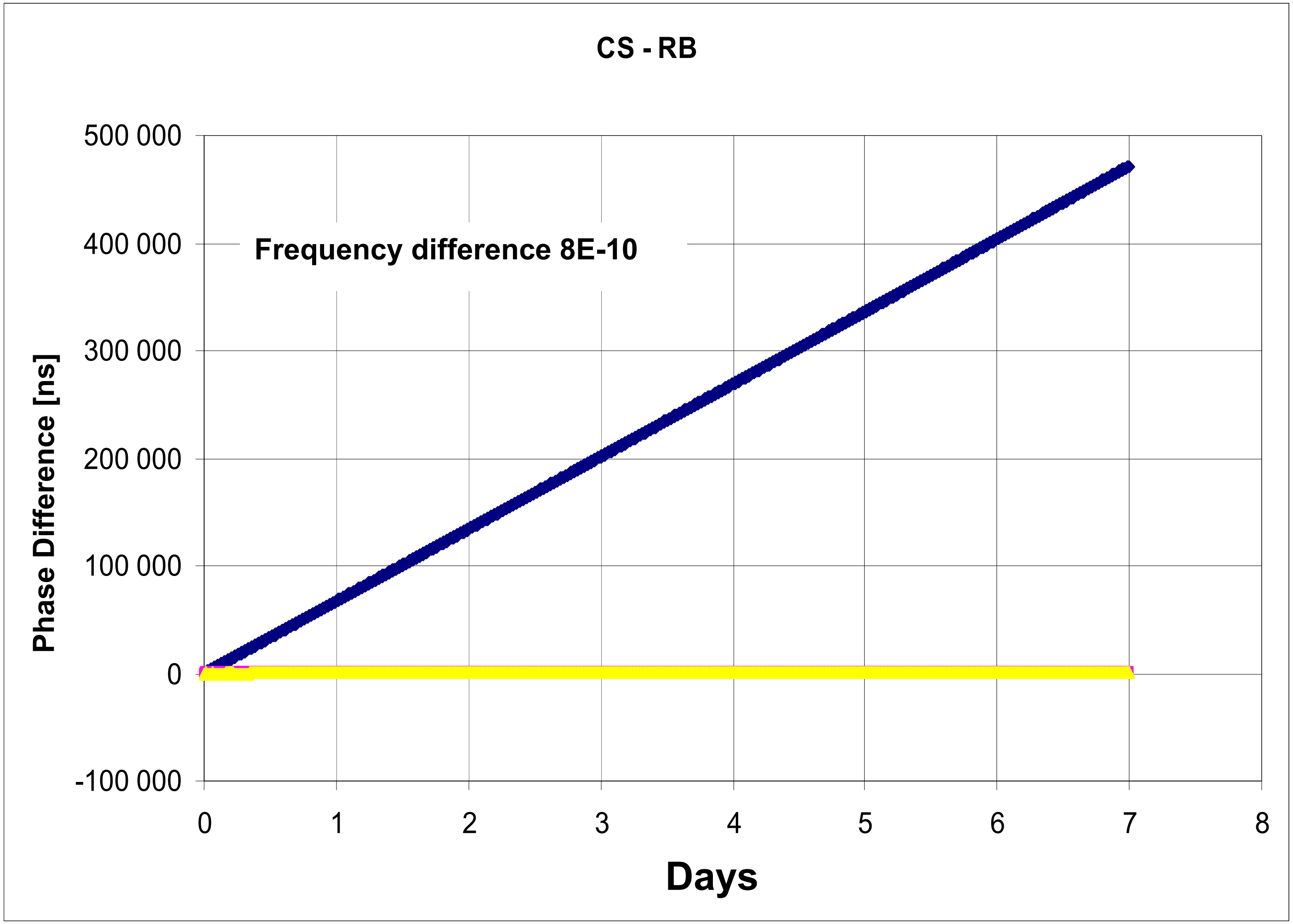


Cesium - Cesium



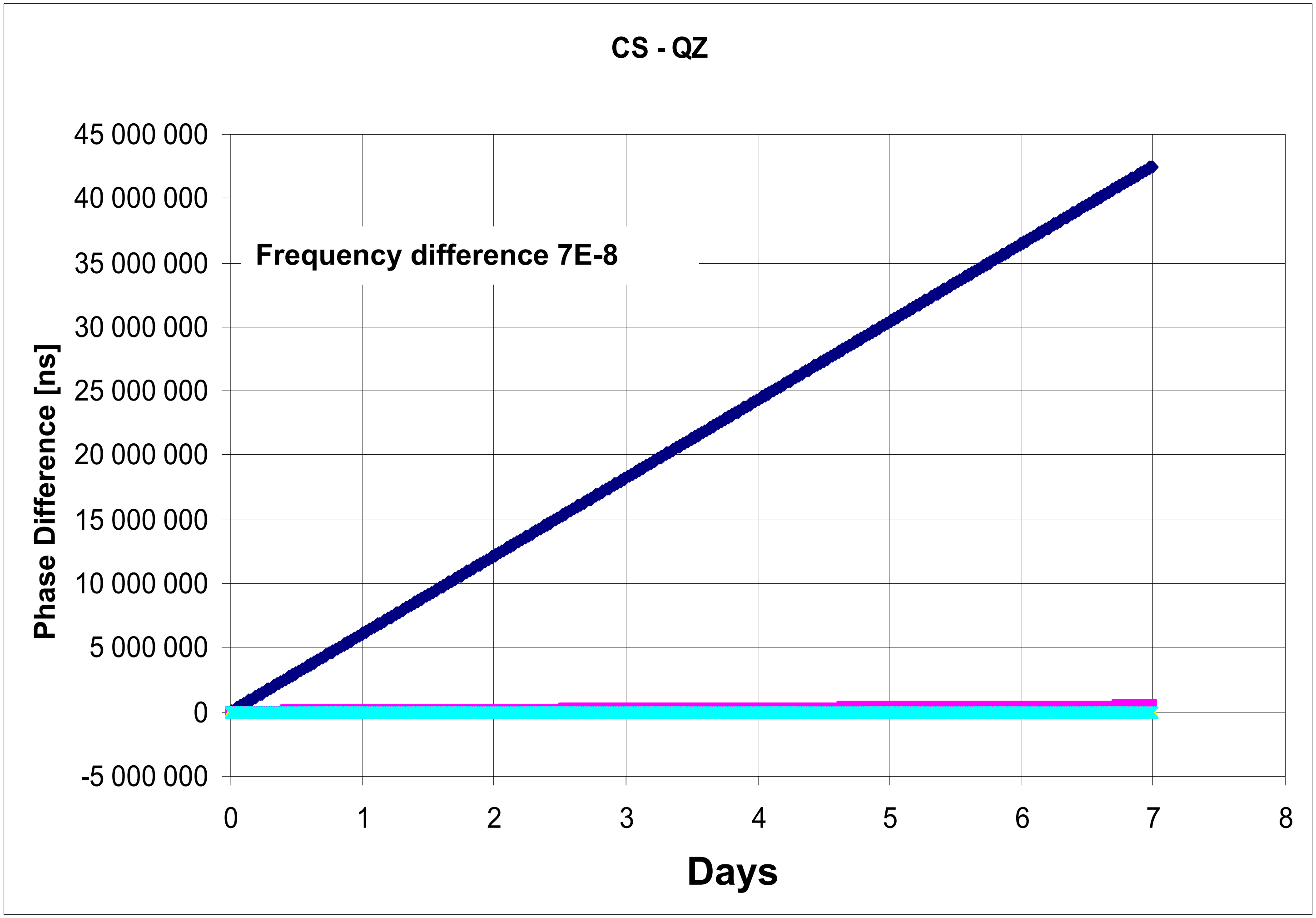
Cesium

Cesium - Rubidium



Rubidium

Cesium - Quartz



Quartz

Host Issues

- We have no standardized way to describe a time and date in todays Internet that can be universally understod and can represent time anywhere.
- Portable applications have to knew how different operating systems handles time.
- Posix (Unix) is neither a linear representation of time nor a true representation of UTC, as the times it represents are UTC but it has no way of representing UTC leap seconds (e.g. 1998-12-31 23:59:60).
- Posix ends Tuesday 19 January 2038, 03:14:07 UTC
- I suggest the IETF facilitates an "upgrade"

TicToc, NTP, IEEE-1588

- Massive confusion: marketeers and industrial and national policy interests:
- One application is ”Time Of Day”
  - Syncronizing events, telling wallclock...
- One application is ”Frequency”
  - Psevdo wires, need to preserve timing from ingress device to egress device
  - Control the radio frequency of a mobile base station
- One application is ”Phase”
  - Syncronize handoffs from one base station to another
  - Triangulate the user handset location, ”911-services”

TicToc, NTP, IEEE-1588

- NTP works without HW support over any network that supports IP.
    - Tries to select the most stable clock
    - Tries to deal with network and local clock characteristics with a PLL loop.
    - Could be improved to nanosecond performance with changes to SW and added HW support
    - Faster CPU’s can do more sophistcated filters
    - Millisecond performace possible on resonable networks
  - NTP is the Internet de facto standard for TOD

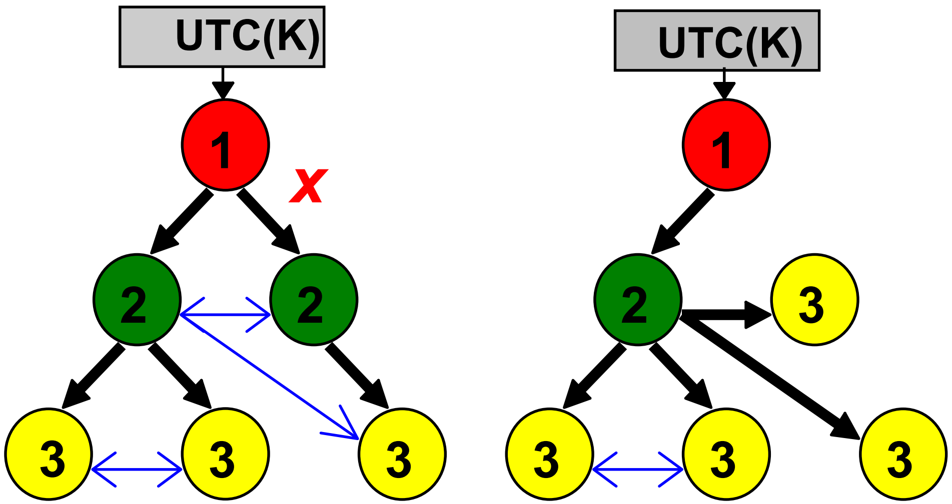
TicToc, NTP, IEEE-1588

- IEEE-1488 requires HW support at the lower layers end to end to perform.
  - If all network elements between the clock source ad the client hace IEEE-1588 hardware support, 5-50ns performance can be archived, but none of that is done by the packet level itself, it's all media dependet HW support.
  - Actual time transfer is done by the Ethernet physical layer
  - The performance drops with the number of devices tracersed, even if they have ”on path support”
  - Maybe we could ”implement NTP” using a IEEE-1588 profile
  - Personally I'm puzzled over the IETF working on something that is not submitted as a internet draft.
  - IEEE-1588 could maybe solve the frequency/phase requirements submitted to TicToc if all network elements had on path support and the network geometry was small

Using the Internet today

- NTP (Network Time Protocol)
  - v3 (RFC-1305)
  - v4 (SNTP RFC-2030)
  - v4 (RFC-?) (Sometimes I don't understand IETF work)
- Daytime Protocol
  - RFC-867
- Time Protocol
  - RFC-868

NTP syncronization topologies



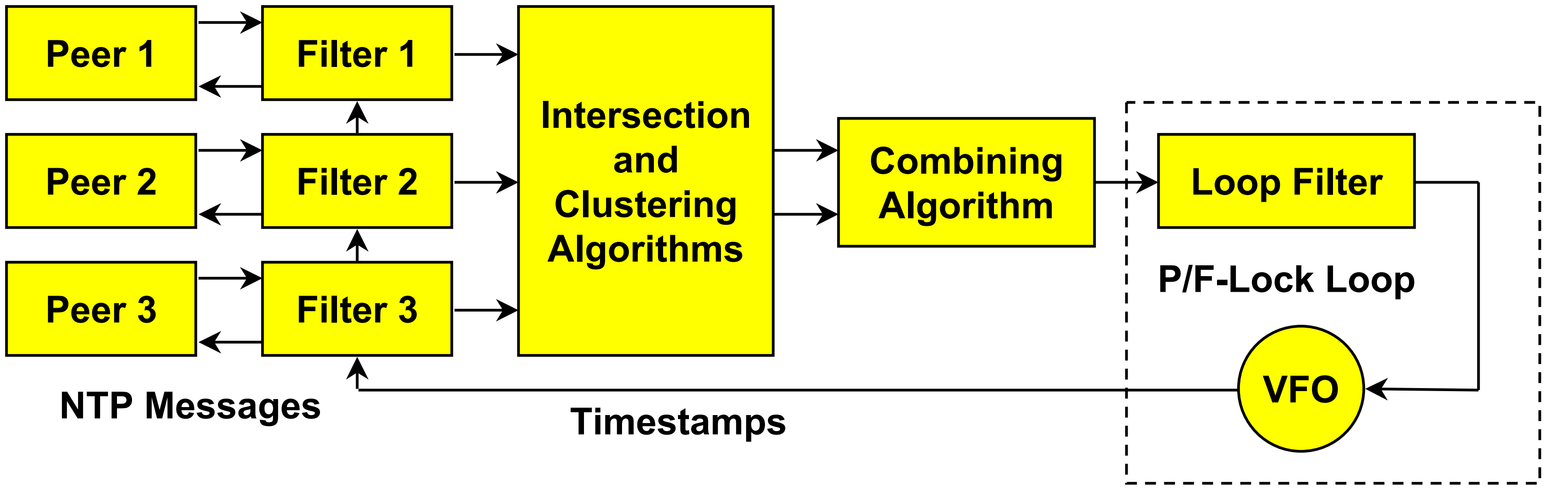
(a) (b)

- Stratum 1 servers syncronizes to UTC(k)
- Stratum 2 servers syncronizes to Stratum 1 servers, etc.
- In (b) is the connectivity marked with *x* in (a) broken
- One server (1) moves from Stratum 2 to Stratum 3

Active syncronizatio relations

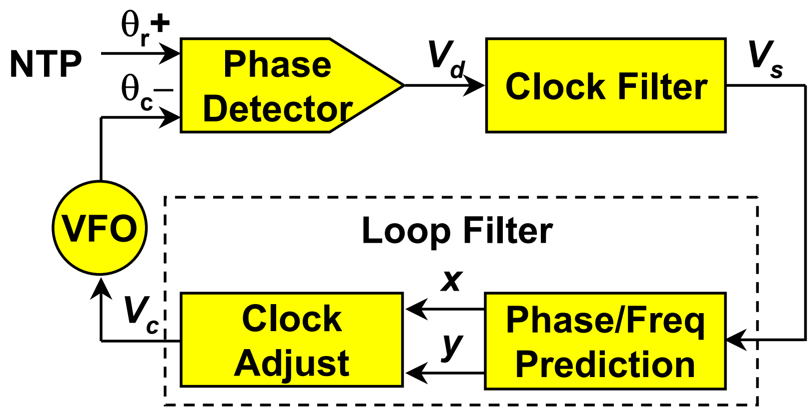
Passive syncronization relations

How NTP works



- Multiple synchronization peers provide redundancy and diversity
- Clock filters select best from a window of eight clock offset samples
- Intersection and clustering algorithms pick best subset of servers believed to be accurate and fault-free
- Combining algorithm computes weighted average of offsets for best accuracy
- Phase/frequency-lock feedback loop disciplines local clock time and frequency to maximize accuracy and stability

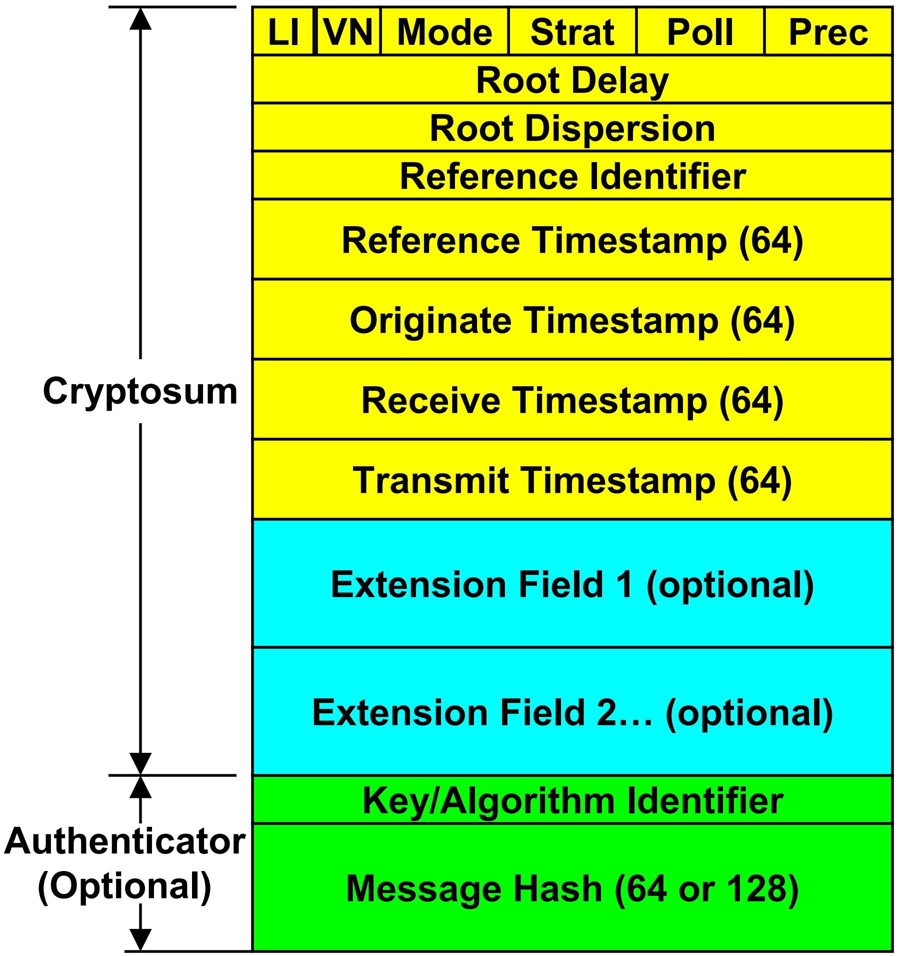
Clock discipline algorithm



- V_d is a function of the phase difference between NTP and the VFO
- V_s depends on the stage chosen on the clock filter shift register
- *x* and *y* are the phase update and frequency update, respectively, computed by the prediction functions
- Clock adjust process runs once per second to compute V_c, which controls the frequency of the local clock oscillator
- VFO phase is compared to NTP phase to close the feedback loop

NTP protocol header and timestamp formats

NTP Protocol Header Format (32 bits)



LI	leap warning indicator
VN	version number (4)
Strat	stratum (0-15)
Poll	poll interval (log2)
Prec	precision (log2)

NTP Timestamp Format (64 bits)

Seconds (32)	Fraction (32)

Value is in seconds and fraction since 0^h 1 January 1900

NTPv4 Extension Field

Field Length	Field Type
Extension Field (padded to 32-bit boundary)	

Last field padded to 64-bit boundary

NTP v3 and v4
NTP v4 only
authentication only

Authenticator uses DES-CBC or MD5 cryptosum of NTP header plus extension fields (NTPv4)

NTP view from a router in Stockholm

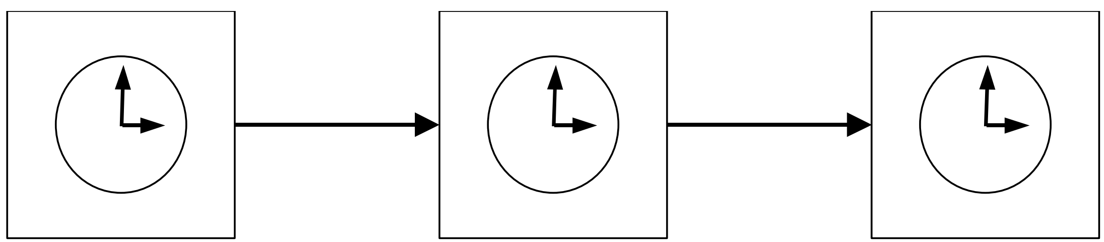
dress	ref clock	st	when	poll	reach	delay	offset	disp
+~192.36.143.234	.PPS.	1	649	1024	377	1.0	0.11	0.0
+~192.36.144.22	.PPS.	1	151	1024	377	1.1	0.03	0.1
+~192.36.144.23	.PPS.	1	223	1024	377	1.1	0.06	0.1
+~192.36.143.164	.GPS.	1	493	1024	377	5.6	-0.38	0.1
+~192.36.143.194	.GPS.	1	577	1024	377	0.8	0.06	0.4
~193.10.7.246	.PPS.	1	839	1024	377	9.3	1.03	0.2
~192.36.133.17	.PPS.	1	790	1024	377	8.3	0.14	0.2
+~192.36.143.153	.PPS.	1	613	1024	377	0.9	0.05	0.0
+~192.36.134.17	.PPS.	1	628	1024	377	11.3	-0.01	0.0
*~192.36.143.152	.GPS.	1	661	1024	377	1.9	-0.04	0.1
+~192.36.143.151	.PPS.	1	626	1024	377	0.9	0.05	0.1
+~192.36.143.150	.PPS.	1	487	1024	377	0.8	0.06	0.0
~192.36.133.25	.PPS.	1	843	1024	377	8.4	0.08	0.1
~192.36.134.25	.PPS.	1	789	1024	377	11.2	0.01	0.1

Local
Stockholm (8 hops) 20km
Boras (6 hops) 540km
Goteborg (8 hops) 600km
Malmo (8 hops) 800km

some 500us without client HW support

IEEE-1588 Boundary Clocks

Each slave synchronizes to its master (based on Sync, Delay_Req, Follow_Up, and Delay_Resp messages exchanged between master and its slave).



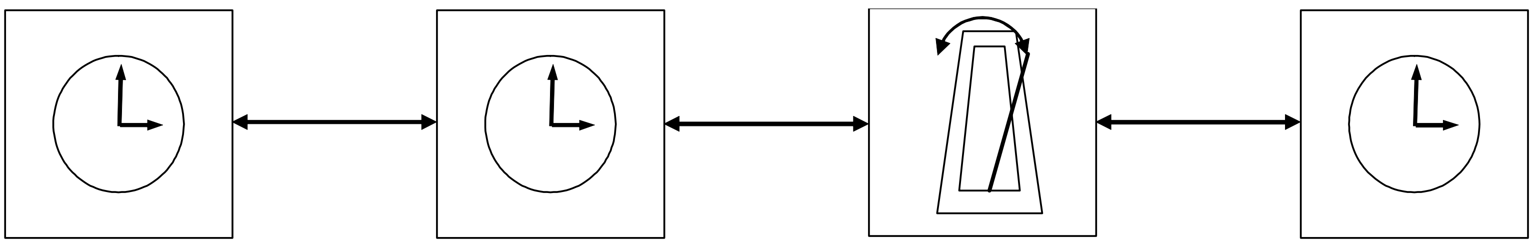
Grandmaster Clock
This clock determines the time base for the system

Slave to the Grandmaster Clock and Master to its Slave

Slave to its Master

The problem with this approach is cumulative errors in the clock servos.

Transparent Clocks



Grandmaster Clock
This clock determines the time base for the system

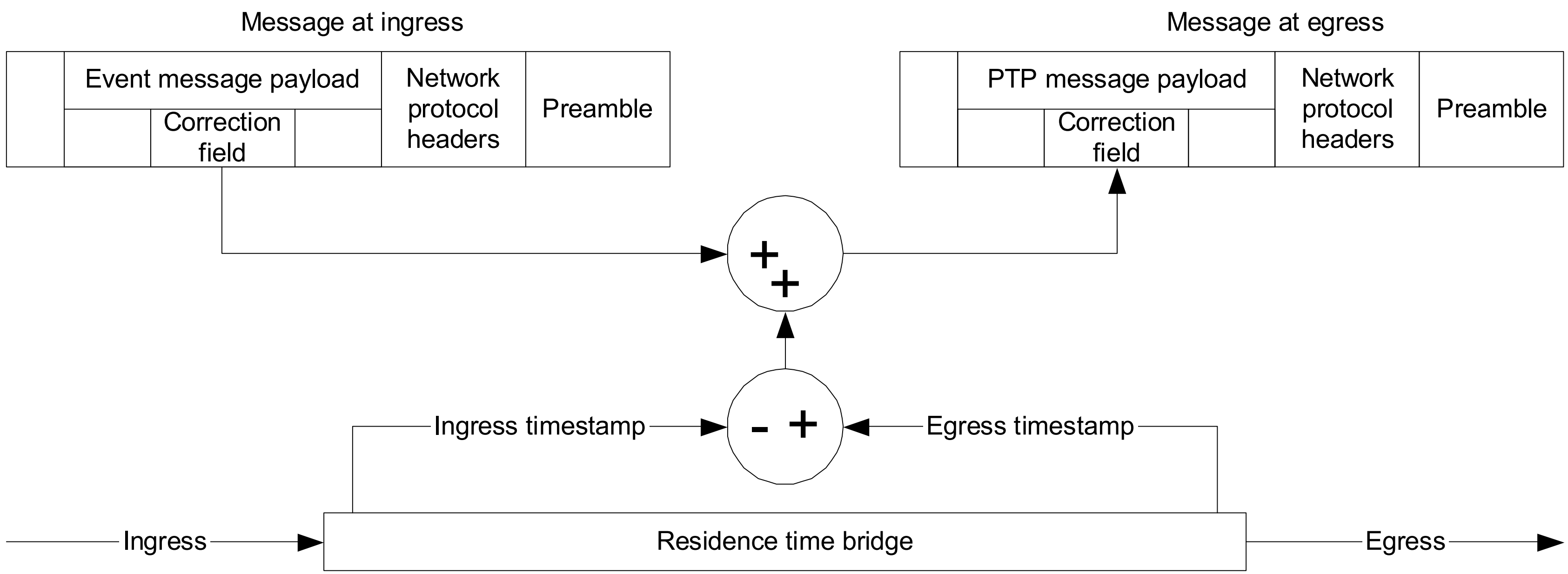
Slave to the Grandmaster Clock and Master to its Slave

End-to-end Transparent Clock (syntonizes to master)

Slave to its Master

A transparent clock applies time correction to IEEE1588 messages that pass through it.

Transparent Clocks

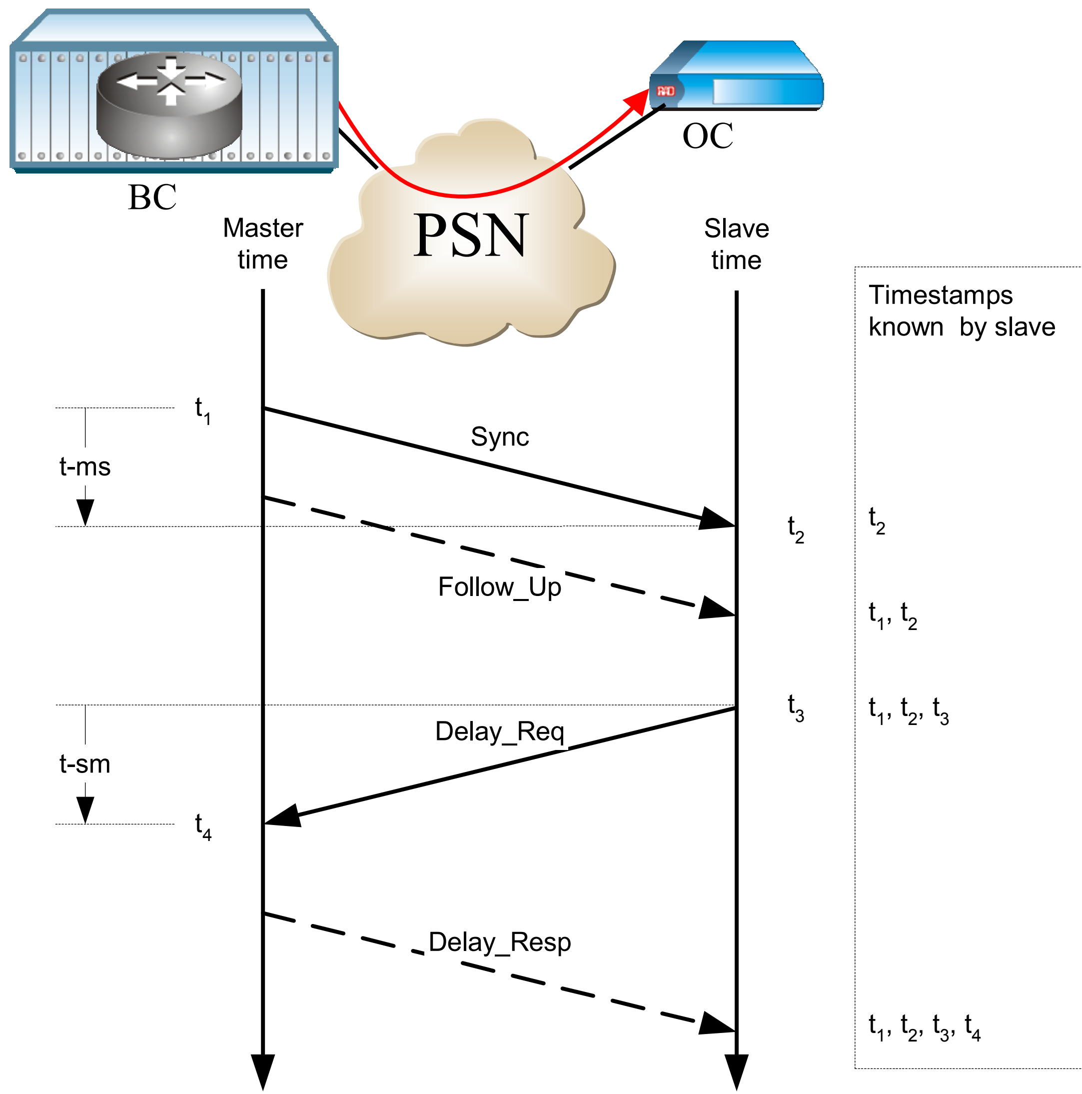


One and Two Step Clocks

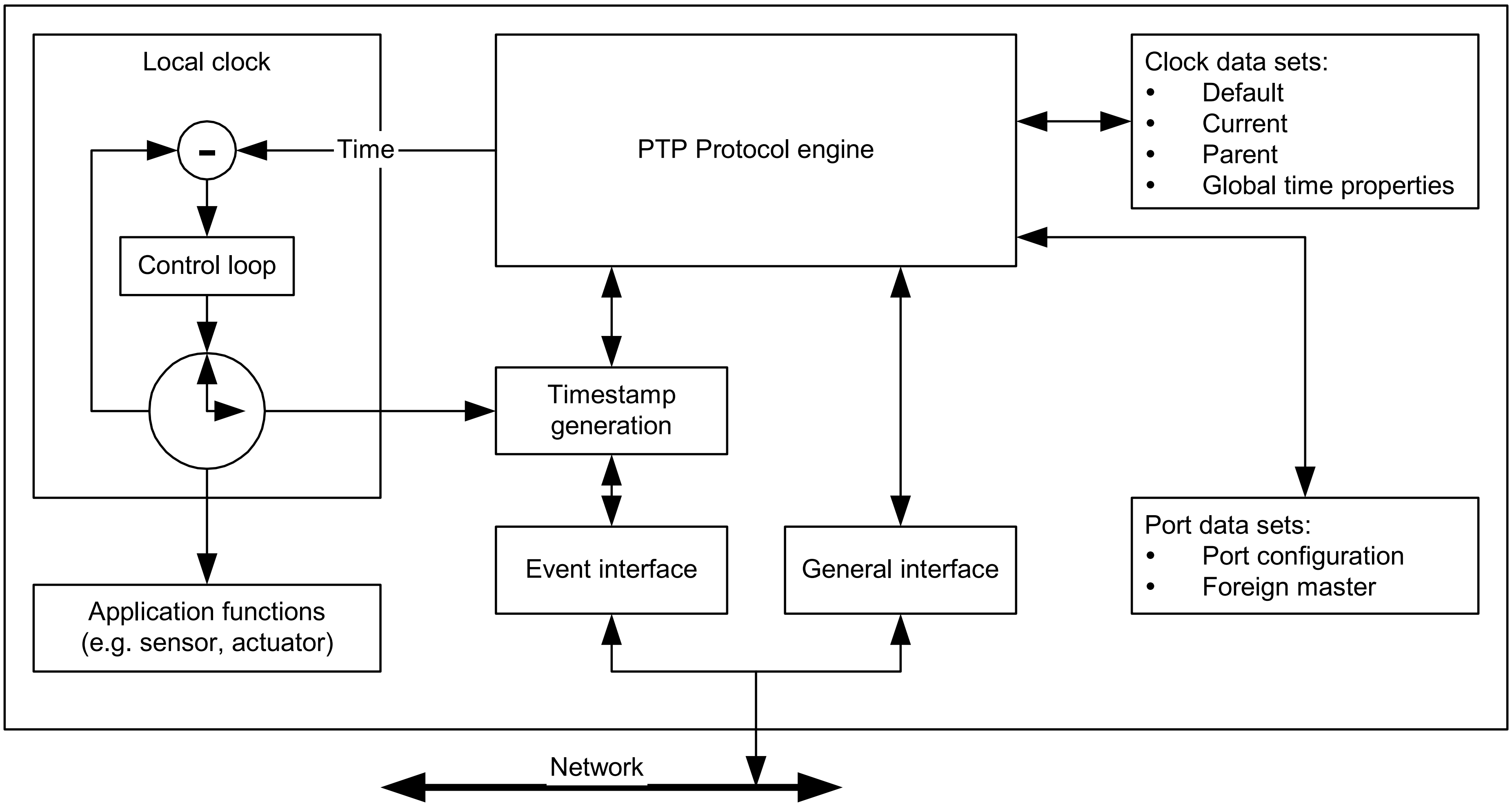
- For maximum accuracy the timestamp in a message MUST reflect the EXACT time at which the message sent.
- This requires hardware support.
- In a one step clock hardware updates (modifies) the message on the fly.
- In a two step clock the message is sent unmodified, but is followed up with a correction message using information gleaned from the hardware.
- Note that the field that needs correction is carried with the PTP part of the message

Delay Request-Response (E2E) Operation

- Implemented on BCs and OCs
- The E2E mechanism assumes symmetry between the M-S and S-M paths.
- Any asymmetry of the paths will introduce an error.
- Measurement of the asymmetry is out of scope of the standard.
- $T_{delay}=(t_4-t_3+t_2-t_1)/2$

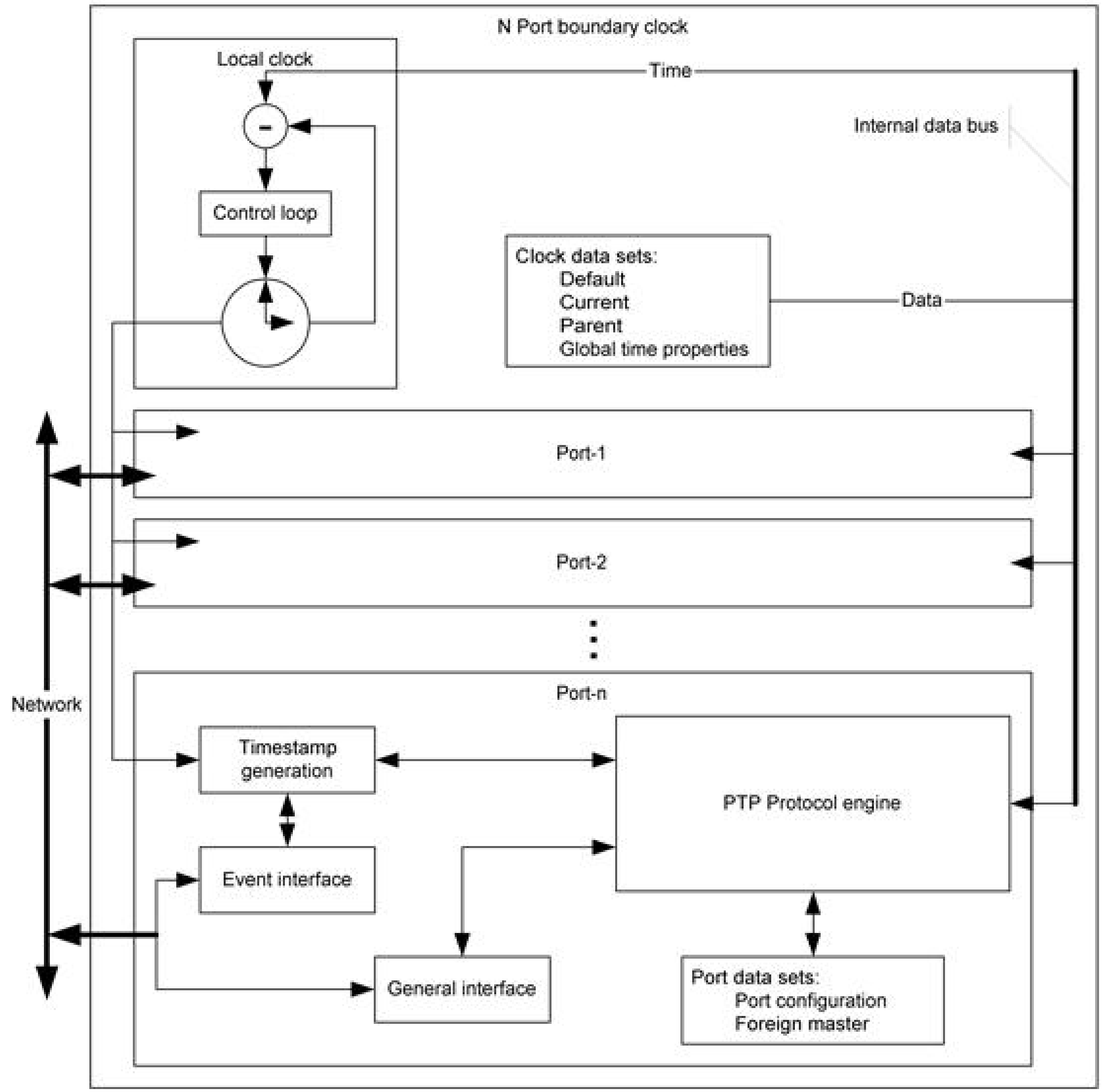


Ordinary Clock Operational Model



Boundary Clock Operational Model

- Boundary clock is an ordinary clock with multiple PTP ports, where, in normal operation, only one port can be set as Slave, the rest are either Master or Passive.
- A Port can be set to Slave Only.



Requirements for wallclock

- Provide the best possible time transfer over arbitrary networks between clients and servers.
- Make use of any available HW support.
- Secure identification of time source UTC(k).
- Secure transfer client-server-client without (too much) server state.
- Identifying size of time errors between UTC(k) and server.
- Capable of handling leap seconds correctly.
- Require no external data (other source of information) to determine the correct time and date. (like 2e32 seconds)
- Standardized API and host representation of time and timescale, Maybe planet independent?
- Wire protocol and algorithms to be separated
- Wire format to support better than 1 picosecond resolution
- Capable of being the basis for future primary time metetrology

NTP improvements for wallclock 1

Possible improvements to NTP?

- Separate Wire Protocol from Algorithms.
  - It has been shown that filter algorithms other than PLL's can archive the same result as NTPv4's PLL does in 60 minutes rather than 1 day
- Maybe we do not want to change the wire format at this point.
  - Installed base
  - Need a way to gain more experience and solve some short term issues
- In NTPv4 messsage typecode 7 is not used. Use it for a TLV encoded extention. (There is also the 4 upper bits in stratum...)
  - Add a 128 bit timestamp that is MJD + 64 bit fraction of day
  - Add a timestamp that is linear time (GPS?, TAI?, NTP-unique?)
  - Add a way to querry a server about status, keys etc
  - Add a way to quesrry server about actual timesoure and charcteristics of transfer
  - Add a way to do secure transfers client-server-client
- Reach out to IEEE/802.* and ask that they make the timestamping mechanisms used by IEEE1588 generic. So timestamps is an Ethernet function for anyone who wants to use it. (NTP, IPPM, etc)

NTP improvements for wallclock 2

Possible improvements to NTP?

- Define a host API for time
  - That has the capabilities needed to support UTC based timekeeping including correct ways of handling leap seconds.
  - Make API capable of stepping, phase and frequency control
- Make it possible to send/receive different length packets.
  - Many users have xDSL and other links that have different speeds in transmitt vs. receive direction. (1000byte @ 1Mbit takes 8ms)
  - Different size packets could be used to estimate speed difference
- Evaluate the possibility of intermediate nodes to participate in the time transfer.
  - ”NTP-Record Route”?
  - ?

Security of public NTP servers 1

- There are Servers and Servers.....
  - UTC labs making their timescale avaliable to the public such as NIST, USNO, PTB, SP, NPL......
  - Organizations that have their own time for all their internal activities that do not need to be syncronized/tracable to UTC(k)
  - Many other applications

- How do we know we are getting the time we expect?

  - I will querry NIST as the government I trust:
    - DNS
    - Already overloaded semantics of an IP address
    - How do you knew your packets actutaly reaches NIST?
    - Man in the middle attack?

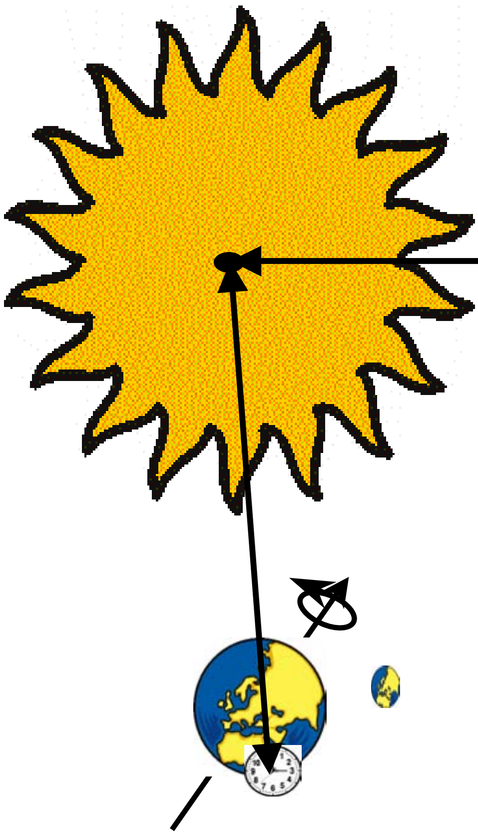
Security of public NTP servers 2

- We need a way to sign the timestamp reply from the server
  - Public key encryption
  - Performance?
  - Key distribution
  - Key Revocation
  - DNS sec?

  ..
- We need a way to secure the communication from client to server and back again, without keeping to much state in the public server
  - Kerberos model?
- What is the IETF recomendation to the time keeping community on how to best provide wallclock to the public for electronic communications, BCP?

When Vint installs Internet to Mars

(About 50 ms/day faster)



Clock and server is a satellite, effected by gravity from other planets. Time transfer has to include information about location referenced to the Bari center for the clock/server and the client/user clock, and it’s infirmaries and other data.

(Hint, time is slower on a bigger planet)

Time distribution/Time dissemination

GNSS (Navigation Satellites) are the market leading method of distributing precision Time.

The Internet is the most flexible way to distribute time to end systems. (Supported by fixed and wireless networks)

National UTC(k) over the Internet is the only practical backup for GNSS based methods.

TICTOC should carefully investigate and document future Internet requirements before jumping to conclusions.